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7th U.S. NAVY SYMPOSIUM OF MILITARY OCEANOGRAPHY

THE PROCEEDINGS OF THE SYMPOSIUM

VOLUME I

NAVAL SHIP RESEARCH
AND DEVELOPMENT LABORATORY
ANNAPOLIS, MARYLAND

7th U.S. NAVY SYMPOSIUM ON MILITARY OCEANOGRAPHY

12-14 MAY 1970 ANNAPOLIS, MARYLAND

THE PROCEEDINGS OF THE SYMPOSIUM

VOLUME I

SPONSORED BY

OCEANOGRAPHER OF THE NAVY

NAVAL SHIP RESEARCH
AND DEVELOPMENT LABORATORY
ANNAPOLIS, MARYLAND

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IN REPLY REFER TO

The Navy's 1970 Symposium on Military Oceanography has been directed toward a greater emphasis on the marine science and engineering problems encountered by the fleet operators. Its primary purpose was to establish a meaningful dialogue and an exchange of ideas between the fleet users and the supporting oceanographic scientists and engineers.

Once again, our annual symposium has produced a number of valuable and pertinent papers on topics which have currency for anyone interested in the vital subject of national defense. I feel the papers which follow will present a significant contribution to the understanding of current fleet oceanographic problems on the part of our supporting oceanographers, and to the increased knowledge of the Navy's oceanographic capabilities on the part of the fleet operators.

On behalf of all who attended the 1970 Symposium, I express appreciation to Rear Admiral James F. Calvert, Superintendent of the Naval Academy, for the use of the Academy's excellent facilities during the meeting; to our host, Captain Andrew Bodnaruk, Commanding Officer of the Naval Ship Research and Development Laboratory; to the General Chairman, Mr. H. V. Nutt, Technical Director of the Laboratory; and to the excellent and dedicated staff at the Laboratory for their superb administration of this very productive symposium.

O. D. Waters, Jr.

O. D. WATERS, JR.
Rear Admiral, U. S. Navy
Oceanographer of the Navy

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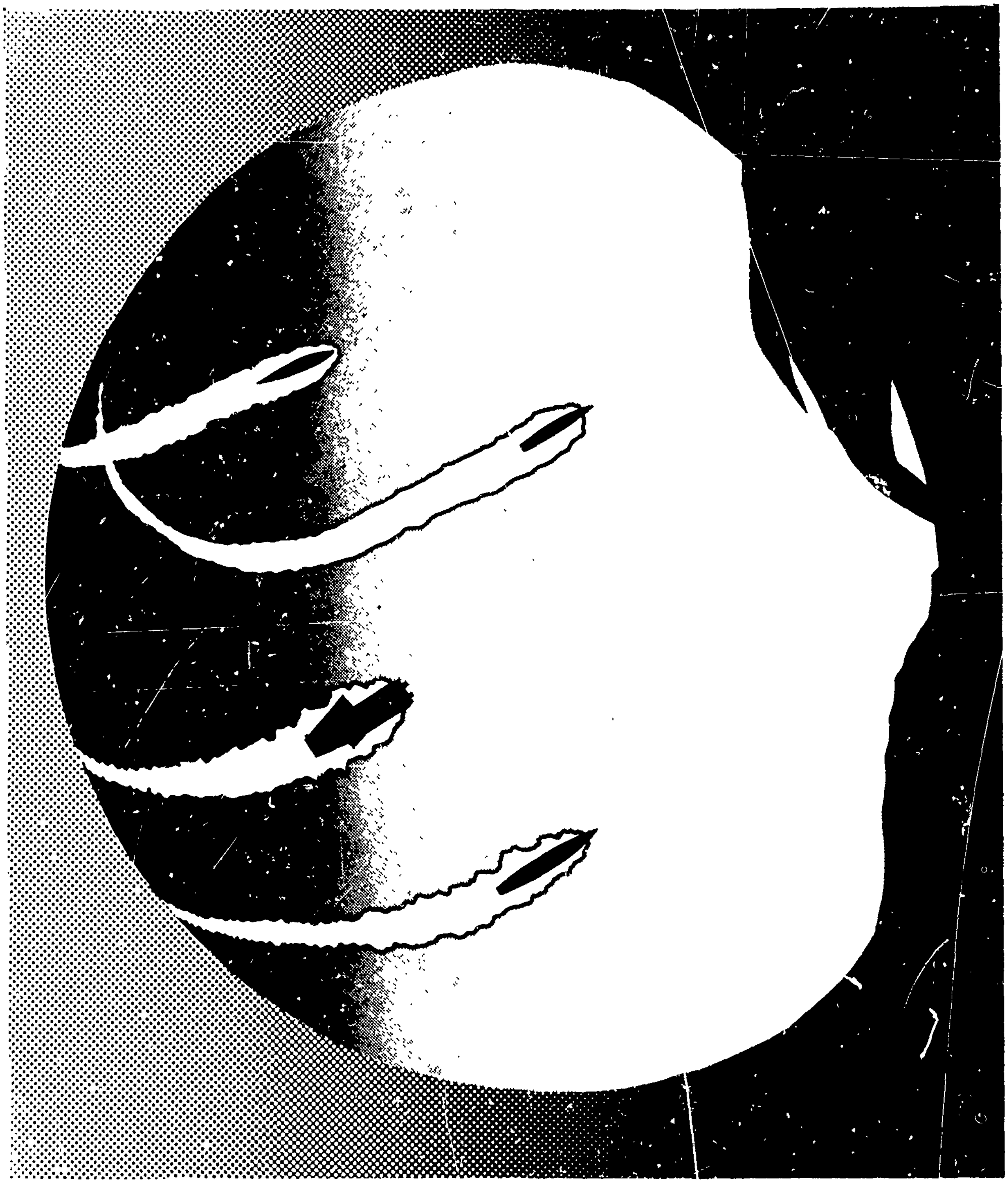

KNOW THE SEA TO CONTROL THE SEA

Opening Remarks by
Rear Admiral O. D. Waters, Jr.
Oceanographer of the Navy

Mr. Chairman, Gentlemen:

Last year at our Symposium in Seattle I promised you some beautiful spring weather for our meeting here in Annapolis and you can see that I delivered.

These predictions of course should be simple for me when I have able meteorologists on my staff to advise me. Actually, however, for this long range stuff I depend mostly on the Farmers Almanac.

Once more I want to thank all of you who took the time to research and prepare the papers to be delivered here and to all of you who have traveled here to listen and learn and to take part in the discussions.

There were numerous excellent papers that could not be put on the program simply for lack of time. Many of these will be published, however, as a part of the printed record of the program proceedings.

At this point I want to express my appreciation to Mr. H. V. Nutt, the General Chairman, and members of his staff from our host organization, the Naval Ship Research and Development Laboratory, and to Admiral James Calvert for making the fine facilities of the Naval Academy available to us.

As you know the stress this year is on the immediate problems of our Fleet operators and what oceanography can do to help solve them.

Fortunately, as sponsor of this 7th Annual Symposium, all I was asked to do was give a short keynote address. Keynote I take to mean a few words about the purpose of the meeting, and some optimistic generalities about past accomplishments and future prospects.

I don't intend however to do either.

What we have done in the past and are doing now is known to you and I suppose we must be doing something right or we wouldn't still be here.

As to the future I cannot speak with the optimism that I felt a short year ago.

The war we are fighting on two fronts - the bitter military battle abroad and the frustrating combination of poverty, pollution and inflation at home - has served to put us in a holding pattern in many areas.

I have no doubt that we will eventually solve our problems and win our wars, but meanwhile the keynote for the government is economy. Major budget cuts are being taken by the Defense Department. And Oceanography has to take its share. This means that many new starts had to be abandoned, survey ships laid up and many programs that were near to fruition have had to be curtailed or slowed down.

I am going to say just a few words about some of those programs - for we seek to protect those most vital to the Fleet - and then I will let the experts take over.

First let me explain for the benefit of some of you new to the field, that Naval Oceanography spans a very broad range of effort - perhaps described best by our three major management categories of Ocean Science; Ocean Engineering and Development; and Oceanographic Operations, which includes our Environmental Prediction Services. All of these areas are represented on the agenda here, and many of the symposium subjects of course include more than one category.

I want to give the status of some of the highlight programs - efforts which we consider of major importance to the Fleet. Programs that we have worked on for a long time, programs where in some cases we are on the brink of significant accomplishments, on the verge of putting the results at your disposal.

In the matter of surveys, we have reached what is known to the trade as Indian Springs Low Water in our capabilities for both coastal hydrographic surveys and deep sea oceanographic surveys, as the last of our military manned survey ships have been stricken this fiscal year. We have four MSTS manned replacements being delivered in the next 14 months, but until they are well shaken down we will be pursuing only very limited coastal surveys, primarily of South Korea.

The next big increase in capability will have to await the completion of development of our high speed coastal survey system which promises to enhance such operations by a factor of 6 or more. We need it - JSOP requirements translate into hundreds of ship years of effort. ASW/USW surveys in support of the SQS-26 and BQQ-2 sonars will be intermittent. We will give full support to Project CAESAR, to insure timely data in support of that project, but as things now stand we will have few resources to apply against other oceanographic survey requirements.

We will continue our Polaris/Poseidon support at a steady level, although that level is not adequate to the need. The FY 72 program contains funds for the conversion of an additional survey platform, which will help immensely in later years. We have contracted with the Coast and Geodetic Survey for about ten ship-months of effort this year, which has relieved the pressure, but next year's funding does not allow this option. Even to generate the contract funds this year we had to give up one of our two aging gravity survey ships.

We have also lost one of our two magnetic survey aircraft, and until fiscal year 1972 when a P-3 type aircraft is shaken down and replaces the remaining plane, we will be curtailing our magnetic surveys supporting ASW and nautical charting.

Many of you have heard that we have laid up relatively new ships, and indeed we do have three small ones in reduced readiness status at MSTS in Brooklyn. We will not be able to reactivate the ships very soon for their original purpose, but we are seeking to place them where the Navy, and if possible our oceanographic programs will benefit from them. We hope to see one operating directly for the Naval Undersea Research and Development Center, San Diego, supporting all that laboratory's projects, while others may go to universities if their operation can be funded by the National Science Foundation, or perhaps to our allies, where we will reap the benefit of the research they support, and perhaps be able to execute joint projects with them.

These have been the operational areas impacted. Let me speak briefly of R&D. Our efforts centering on Deep Submergence have noted milestones, but many have also undergone significant modification. Our man in the sea effort, for example, is no longer habitat oriented, but rather is being conducted as a cautious, three phase project utilizing a Mark II Deep Dive System. The modified project will achieve virtually all the original objectives, however. We do not intend to refurbish the habitat until we launch our extended depth Man in the Sea project, probably in 1973.

Our Deep Submergence Search Vehicle project has been redirected towards the long lead time technology, and fiscal 70 funding is being stretched to cover 71 effort.

We feel confident that a successful development is within our grasp, but the fiscal climate is just not right. Our related Deep Ocean Technology, or DOT, project continues to receive emphasis, especially in the areas of hull materials and power plants, and we look to that project to keep us in maximum readiness to respond to many deep ocean system requirements when funding allows.

As you know the first DSRV was launched in January, and tests have been successful so far. We expect to implement an interim rescue capability by this time next year, if the current construction program for the catamaran ASR holds. The nuclear research vehicle NR-1 has also recently completed a highly successful 30-day shakedown cruise, obtaining much oceanographic data of interest.

Our salvage capability continues to improve, and last month, in a test of a new deep dive system, Navy divers worked at 650 feet depths very successfully for three hours. We are attempting to implement a serious effort on a large object salvage system, a project which has been on the back burner for several years, for again the technology seems to be within our grasp.

The backbone of the submarine finding brigade, the USNS MIZAR, just excelled again by finding the French sub EURYDICE. It is remaining in the area at the request of the French to seek the sub MINERVE, lost over a year ago. MIZAR, with its NRL scientists, is a truly remarkable platform, but it is only one system and there is a big ocean out there. Disasters will have to occur serially, not concurrently, or our lack of resources will come home to haunt us.

In recent years we have been able to mount some really intensive field experiments concerning the environment and its relation to underwater sound. These in turn have led to substantial successes in modeling the environment, and we are on the verge of great things in this area. But progress will depend heavily on our continuing strong program of at-sea experimentation, as well as on an increased density of routine environmental data reports from ships at sea.

This improvement in modeling has been paralleled by a major step in forecasting services to the Fleet, with the introduction by the Naval Weather Service of its ASRAP and SHARPS products. We feel that we are on the right track and intend to concentrate on the further evolution of the systems.

Turning for the moment from functional to geographic areas, I'll mention that the states of our knowledge of both the Arctic and Mediterranean have recently been bucked against our requirements, and as a result both areas are to receive increased emphasis immediately.

To this decision, many of us say "high time," but in fact our low level programs have formed a solid foundation for the expanded effort. For example, there have been some exciting improvements in sea ice reconnaissance and forecasting, using both satellite and aircraft sensors, and we have given a high priority in recent years to the military construction which has upgraded the Navy's Arctic Research Lab.

There are other important milestones on the horizon such as the coming into operational status of our two new submersibles SEA CLIFF and TURTLE, and the delivery of our catamaran research ship HAYES, the AGOR 16, which will greatly enhance the acoustics research capability of the Naval Research Laboratory.

There are also a large number of requirements, both existing and forecast, with which we must come to grips. I have tried to set a background for you to use in the discussions to follow, for requirements are expected to permeate almost every agenda item. I have tried not to sound too pessimistic, for we still wield a major capability. It is of the utmost importance that requirements continue to flow from the Fleet, for only through the knowledge of such requirements can decisions on the resources to fulfill them be made. However, it is equally important that the priority of those requirements be carefully assigned and regularly reviewed, and that requirements for such effort as the Fleet deems most vital to its current and future operations be pushed by them and at every level of the Naval Establishment, in order to insure that the oceanographic program which is accomplished is of maximum benefit. As I've tried to indicate also, there is daylight at the end of the tunnel, but the tunnel is a long one - for us, probably, fiscal 73 will see the first relief.

I'll close by reiterating that our problems are no different from those of the rest of the Navy. We are all caught in the draw-down. However, in times like these we in Oceanography must really produce more, for knowledge and exploitation of the environment are one important key to improved performance by the ships which are left in the operating forces. Further, much of what we do can only be done in peacetime, when the environment is accessible. These factors dictate our continuing efforts to insure a place in the Navy for a strong oceanographic program.

MARINE SCIENCE CAREER PLANNING - A FEW BIG IF's
By
Robert B. Abel
National Science Foundation
(Luncheon Address, Tuesday, 12 May)

Once upon a time, a career in ocean science was a delightful subject for conversation, but now, at a time when marine science and technology is being subjected to its most critical examination, manpower questions seem particularly to vex federal bureaucracy and to intrigue analysts.

What's an oceanographer? How many oceanographers are there? How many oceanographers ought there to be? Do oceanographers have a place in industry? Are they being educated correctly? Will engineers be needed more than oceanographers? How many technicians are needed to support a professional oceanographer? Who is training technicians? What is the supply/demand ratio for oceanographers, ocean engineers, and ocean technicians? What will this ratio be ten years from now? What ought we to be doing about this problem? Is there really any problem in the first place?

These questions, which have been asked repeatedly since the turn of the decade, dramatically acquired new importance when the ocean was suddenly discovered to be part of the environment.

Perhaps one reason for the seeming devotion of analysts and reviewers to this particular aspect of the national oceanographic program is the apparent ease with which we can play the numbers game. Compared to questions such as "what is the worth of our research program in marine biology?" issues relating to numbers of people seem to be relatively straightforward. It is only when the process of statisticizing actually begins that we begin to realize its true complexity. While perhaps a dozen or two head counts of various kinds have been made over the past eight years, the answers don't really appear much clearer now than before it all began.

The dilemma is linked to the history of the National Oceanographic Program, with which I'll assume you to be familiar, at least in its earlier research phase, in the 1940's and 50's.

Later in the 1960's, however, as Federal authorities and their coordinating bodies in marine science took time out for some honest soul searching, they concluded that it was about time that the tax payer received more obvious returns on his increasingly heavy investment - specifically, toward what applications should ocean studies now be directed? This utilitarian aim had the connotation of making things work in the oceans and thus was born the phrase "ocean engineering." From the not yet matured community of oceanographers there now emerged the ocean engineer, and although few universities had had ongoing programs in technology, several of them now began to think in terms of sophisticated fishing techniques, aquaculture, ocean mining, pharmaceuticals, etc. This, of course, further complicated the education and training problem since schools of fisheries, mining, and public health were wheeled into action.

Introduction of the Social Sciences

Naturally, at this point state governments and industry decided that they too wanted a piece of the action and organized and recruited accordingly. It now became apparent that science and engineering offered only partial solutions to the problem of exploiting the ocean - the fact had to be faced that the problems are largely institutional in nature and require social science treatment, e.g., law of the sea, economics of resource recovery, program administration, etc.

This new concept had led to a minor rennaissance in scholastic planning. Schools of public administration are currently looking to the oceans for important new topics upon which they may concentrate attention. Graduate students have been assigned research studies in resource recovery problems, economic planning, waterfront development, etc. This three dimensional (natural science/application/social science) matrix has much in its favor, allowing for the first time logical and comprehensive urban and economic planning studies which not only begin to consider water areas but even sometimes start with them, developing landward.

At the present time, realistic examination of the education problem could easily lead to massive coronaries on the part of university planners. The student now confronts an academic meat grinder in which he is to partake not only of traditional morsels of chemistry, mathematics, biology, geology, and physics, related to oceans; he is not tempted by engineering possibilities inherent in ocean development. Formal engineering curricula demonstrate irresistable expansion, responding not only to explosive growth of new science and technology, but also thethe pressing demand for better understanding of social sciences and humanities. Incidentally, it is proposed that this burgeoning academic demand upon the student is partly responsible for development of a growing gap between functions of the highly educated engineer and those of the skilled mechanical grades. For instance, several junior colleges have become interested in training ocean technicians, who would assist scientists and engineers in nearly all phases of ocean science and technology. Such jobs include operations and observations at sea, the more elementary analyses of oceanographic data, design and fabrication of instruments, and of course, assistance in training other technicians. While only one or two schools had recognizable curricula for training ocean technicians prior to 1965, at present, about 20 schools can be identified in at least the curriculum planning stages.

Now, just to show you how cruelly you can lie with statistics if you really set your mind to it, a recent report of a California survey projected nearly 4,000 technical job openings over the next five year period in 80 organizations in California alone. These openings were identified as marine-related technical jobs and the average median annual salary was listed at over $7,500. Although some of the jobs were held by persons with bachelor's degrees, most of them were being occupied by technicians at non-degree levels. But - a still more recent follow up disclosed this figure to be almost 3 times too high!

To summarize the history of ocean education in a sentence, two generations have watched a succession of expressions of need for scientists trained in basic disciplines, for oceanographers and very recently for ocean engineers, technicians and social scientists.

This brings us to the present when the ocean's press notices conflict with reality. As a long time member of the oceanographic community, I'm afraid that in the early years I did my share of drum beating. It seems that we promoted so well however, that most people are still convinced it is only a matter of days or weeks before vast sums of money are poured into the oceans, to fulfill the excited promises of the communicators or - that is - all realistic estimates to the contrary.

It isn't going to happen.

Ocean development will take place, because it must. We need the products of the sea, and we need the sea itself as the principal source of the oxygen we breathe, and as the regulator of our climates. We need to understand the sea to understand our planet. We need sea business and industries to keep our economy growing. We also need marine conservation, and the preservation of great areas of sea and shore as natural preserves.

We will probably get these things one day. But we will get them from evolution - gradual growth - not from revolution or a sudden explosion.

What has happened to the truth about ocean development is the same thing that has happened to money - it has gotten inflated. A good example of that inflation is a statement made in a recent book about marine careers. The author predicted 100,000 new marine jobs by 1980.

He may have been right - but if he was, the jobs won't be the kind he predicted. And that comment leads us from the inflated image of marine development to a second false image.

Just about every publication on the sea, or on marine activities, stresses the scientists of the sea - those whom we call oceanographers.

We hear a lot about oceanography through our public communications media - so much, in fact, that we have come to look on oceanography as a science. It isn't; it never was (even though I've been referring to it as such). What oceanography describes is a place - the sea - not a science. So, to reply now, to the questions I posed a few minutes ago, an oceanographer is a scientist who learned first to be a scientist, and then applied his basic knowledge to the special problems of the sea. Usually he did this in graduate school, earning a master's degree or a doctorate. There are exceptions, of course, but they are becoming rarer, not more common.

To be an oceanographer today practically requires a doctoral degree if one is to gain recognition and good employment. Again, there are exceptions. People of unusual brilliance and talent sometimes can make it without such credentials. But, and here's an honest clue, friends: most of us aren't that brilliant or talented.

There are physical, chemical, geological, and biological oceanographers, but - at least among the good scientists - the distinctions blur. For instance, a biological oceanographer can't understand the population dynamics of fish species, or he can't understand the vital food chains of the sea, unless he has good knowledge of the physical behavior of the sea, its chemistry, and geology. A chemical oceanographer can't really comprehend the organic chemistry of a body of water without knowing its physics, geology, and biology. More than in any field, the oceanographer, regardless of his basic specialty, must be a generalist - a jack of all sciences. And that takes a lot of learning, and a lot of experience. That's one reason why a doctoral degree is practically essential.

One of the Sea Grant Panelists, Dr. Burr Steinbach of Woods Hole, says that it's the broad people who make the real contribution to marine science. Anyone can be a narrow specialist - maybe an authority on codfish whiskers. It's safe to do this. If you're the world's foremost authority on the growth rate and structure of codfish barrels, no one will argue with you. But how much of a contribution is it?

And, make no mistake about it, making a contribution to human ability to understand the sea is important to oceanographers. To put it bluntly, it's a lot easier to make a living on land, and usually one makes a better living. It doesn't mean to be money that attracts Sea People. First of all, it's the attraction of the sea itself, its complexity, its mystery, its ever-present beauty. Even during great storms, the sea is awesome, with a strange, terrifying beauty - if you're able to appreciate it.

Just about a month ago, the Research Vessel ADVANCE II left Cape Fear Technical Institute to go to Virgin Islands, as surface support ship for Project Tektite II. The ship stuck its nose out of the Wilmington River into a storm. It wallowed at reduced speed for three days, and of the more than 60 people aboard, only five were seasick. The Captain himself got sick. But he stood his watches, his face greener than the sea around him. And so did the technician trainees, and the crew, and the scientists aboard. That's the way it is at sea. Only passengers have the privilege of taking to their bunks and enjoying the prospect of the ship sinking, hoping it will put them out of their misery.

As it turned out, just as the ship cleared the storm area, one of the kids aboard became sick, seriously so. The ship radioed the Coast Guard, which recommended they put into the nearest port. The weather was too bad to send a helicopter, and too choppy to transfer the boy to a cutter at sea. So the ship had to turn around and steam back through the storm, because the nearest port was at the mouth of the Wilmington River - from which they had sailed. It's times like this that causes oceanographers to call themselves "scientists who get seasick."

Let's now look at the situation for the oceanographer.

First, oceanographers always will be a minority among the Sea People. A greatly expanded ocean program will mean a need for more oceanographers, but not many thousands. There wouldn't be enough ships, laboratories, or tasks to serve them. At present, about 1800 oceanography and ocean engineering students already are in graduate school. Unless the Federal Government starts putting more money into oceanography pretty soon, those students are not going to have an easy time finding jobs when they emerge from the education pipeline with their brand new degrees in hand.

In fact, there is a shortage of jobs, not people, in some specialties right now. We have more biological oceanographers than we can profitably employ. We have more geological oceanographers. There may be room for a few more physical oceanographers, and there is room for more chemical oceanographers - and the reason for this is quite simple: Normally it takes longer to get a degree in physics or chemistry. On the other hand, jobs may open up in another direction, and the face of the oceanographer will change, somewhat.

To begin with, many of the problems we face in the coastal zone, in the estuaries, and on the high seas are not scientific or engineering problems. The most serious problems are legal, economic, sociological, political, and cultural.

When we really begin to expand ocean activities, it may be private industry, not the Federal Government, that will assume leadership. The Federal Government's largest role will be in providing essential services to the real developers and users of the ocean. Some of those services will be research, surveys, forecasting, and safety. And, of course, regulation. Federal services will provide a base.

To build on that base, industry must operate legally, and economically. The legal situation is so fouled up at present that it's hard to start anything new. Anytime some businessman tries something new, it's apt to end up in a court case. Yet, there are very few lawyers who really understand marine law - the law affecting use and development of nearshore waters and the continental shelf. We will need many more sea lawyers - not the old Admiralty type, but a new breed.

Many new activities fall down when it comes to economics. Business and industry have to show a return on their investments. Most of the big opportunities you've heard discussed break down when it comes to economics. Take ocean mining, for instance, We know minerals exist at sea - both manganese nodules and place deposits of important minerals. If they're to be used, the mining industries must make money from recovering the processing them. At present, even low-grade ores on land show a better return than most sea minerals. By the way, those manganese nodules we hear so much about are important for the copper and nickel they contain - not for the manganese. But, at present, it would cost more to recover nodules from more than a mile of water than the miner could get for selling them. This will change, but we don't know when. We need economists and business administrators to work on the problem. It's always hard to find excellent marine business managers. It's a lot easier to find scientists and engineers. Well, so much for the kinds of people - not let's look at numbers.

In attempting to look to tomorrow, I must emphasize that for the forseeable future, funding for marine science will mostly originate in government. Industry's strong, but distant role notwithstanding. This may, unfortunately, lead to further pessimism. Federal budgets in marine science during fiscal years 1965-1969 rose from $425 million to $471 million, an increase of about 12%. During the same period the number of advanced degrees annually awarded in oceanography about doubled.

Some figures could lead to surmises otherwise. For instance, increasing enrollment could imply faculty shortages, as more teachers are needed to handle the increases in student populations, but this shortage will be quickly overcome as the output of new doctorates has its impact. Of more serious character will be space and facility shortages, as growing requirements encounter strengthening resistance of Federal budgeteers to expenditure of agency funds for "bricks and mortar."

Even the most biased observer could hardly claim any compatibility between the growth curves for the marine science budget and student enrollment, respectively. The question might legitimately be asked, "Whence will come supplementary funds for sustenance for these new people?"

For a look at significant events of the past year relating to marine science manpower, it is not necessary to dig very deeply - it has been an eventful year.

In December '68, UNESCO and the Intergovernmental Commission on Oceanography convened a working group on education and training in marine science and technology. The group reviewed the general oceanography manpower situation throughout the world and concluded that the real manpower shortages are in the developing countries which cannot afford training and salary costs.

The long-awaited report of the Commission on Marine Science, Engineering, and Resources, released on January 11, 1969, included no dramatic conclusions or recommendations respecting education and manpower, suggesting merely that: "The National Oceanic and Atmospheric Agency (NOAA) be assigned responsibility to help assure that the nation's manpower needs are satisfied and to help devise uniform standards for the nomenclature of marine occupations; The National Science Foundation expand its support for undergraduate and graduate education in the basic marine-related scientific disciplines and plan post doctoral and mid-career marine orientation programs in consultation with the academic and industrial marine communities; The NOAA (National Sea Grant Program) expand its support for ocean engineering and marine technician training at all levels and that it aid selected universities in organizing graduate level education in the application of social sciences to marine affairs."

None of the Commission's findings related to "what is" - only to "what should be." Their statements become realistic only when viewed against the backdrops of a national agency, sharply increased funding, or both. Under the Pell/Rogers Act National Sea Grant Program already supports curricula of ocean engineering education at the bachelors', masters', and doctorate levels at 15 universities, encompassing some 400 students. Over 400 marine technicians are being trained under Sea Grant auspices at another 15 community colleges. Future planning depends on feedback, i. e., it is unlikely that Sea Grant support will be extended to any more schools until next month's employment data are analyzed.

Finally, as another way of assessing the future, the possibility of forming a National Agency for Oceanography - a NOAA - is held out, as the panacea to cure, not only the manpower problem, but all problems associated with ocean development. Frankly, I'm afraid that formation of a NOAA,if such should really come to pass, will not make for a whole new ball game.

Indeed there may be little or no reason to expect that consolidation of several existing oceanic programs into a single agency will automatically confer on this agency preferred funding status. Accordingly, I really do not see a sudden bloom of oceanographic effort being put forth by our nation in the foreseeable future, nor the consequent burgeoning demand for oceanographics which such an effort would create.

Thus, there will probably be a buyer's market for some time to come - plenty of oceanographers, but not so plenty of jobs.

THE SIGNIFICANCE OF MARINE BIOLUMINESCENCE IN SOUND SCATTERING LAYER MIGRATION

Midshipman Dudley W. Leath
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ABSTRACT

A study of existing data on bioluminescence in the sonic scattering layers has led to the formulation of a more refined hypothesis to explain the migratory cycle. It is based on the concept that biologically produced light may provide a contributory impetus to diurnal vertical migration.

At present it is suspected that the change of sunlight intensity, with respect to depth, controls this migration. The new hypothesis contends that migration along isocontrast lines may result from the attempt of biological populations to camouflage their own luminescence while still being able to respond to the luminescence of their prey. The theory thus requires that luminescence acts as a lure to predator organisms. Research in this area may lead to the development of a method for the passive detection of sonic scattering layers through measurements of bioluminescent intensity.

INTRODUCTION

Marine bioluminescence and the daily migration of biological sound scattering layers in the sea have been known and studied individually for years. Measurements of bioluminescence made at scattering layer depths, however, suggest that these two phenomena are intimately related. Review of the existing data on this relationship led to the hypothetical conclusion that marine bioluminescence may provide a contributory impetus to diurnal vertical migration of sonic scattering layers.

The most common organisms suspected of scattering 12 khz sound and producing the layer that is normally seen are small mesopelagic fish called myctophids. Usually located above the myctophid layer is a population of macroplankton consisting predominately of euphausiids. These shrimp-like crustaceans grow to about 2.5 cm. in length and may produce an observable sound scattering layer when higher frequencies are used.

Both myctophids and euphausiids are known to perform extensive vertical migrations, migrating downward to depths of 600 to 800 meters during sunrise and upward toward the surface during sunset. Clarke (3) correlated this migration to the movement of isolumes, lines of constant light intensity, calculated from measurements of surface irradiance and transparency of the water mass. Today, however, it is more commonly believed that sonic scattering layers migrate in response to a relative change in light intensity (12, 1, 4).

Studies made in support of this theory do not consider the possible effect of bioluminescence as a lure to predator organisms. Food chain relationships suggest that myctophids and euphausiids have learned to associate luminescence with food. Each possesses light producing organs, called photophores, located along the length of its body. The myctophid layer is an excellent food source for larger mesopelagic fish. Myctophids, in turn, feed predominately on euphausiids, and studies have shown their guts to be full of the shrimp-like crustacean when examined after the layer ascended in the evening (6). Similar studies performed by Mauchline (9) indicated an increase in the percentage of dinoflagellates,

Superior numbers in parentheses refer to similarly numbered references at the end of this paper.

highly luminescent phytoplankton, in the stomaches of euphausiids during the same period of migration. Dinoflagellates are a heterotrophic form of life found predominately in the euphotic zone, where light is available for photosynthesis. Many investigators, however, have discovered deep living dinoflagellates and phytoplankton (11) suggesting that these organisms may be available throughout the water column inhabited by euphausiids.

Measurements made of bioluminescence at scattering layer depths have shown that this organically produced light is coincident with zones of sonic reverberation. A study made on the sound scattering layer in the San Diego trough recorded a mean frequency for luminescent flashing in the layer of 32 flashes/min. during the night, 10-24 flashes/min. throughout the day, and 42 flashes/min. during periods of twilight (8). Laboratory experiments suggest that the increase in luminescence during periods of vertical migration and during the night is due to increased swimming activity in the scattering layer. The swimming motions and feeding of mysids, an organism very similar to the euphausiid, placed in a tank with dinoflagellates produced an increase in the level of luminescence (7). Also, when free swimming euphausiids and myctophids were placed in an aquaria, active bioluminescent flashing was recorded (10).

Kampa and Boden (8) studied the movement of a scattering layer in the San Diego Trough over a two year period measuring the light intensity at depth with a photomultiplier tube. They found that the layer followed an isolume with a mean intensity of 10^{-4} uw/cm^2. As the layer ascended in the evening, it appeared to migrate toward the surface at a faster rate than the isolume it normally followed throughout the day. Numerous bright flashes of bioluminescence were recorded at this time. Boden and Kampa (2) noted that these may have obscured the true relationship between the depth and the amount of transmitted surface irradiation. These observations indicate that isolumes cannot be calculated accurately from measurements of surface irradiation and transparency alone, as was done by Clarke (3). Measurements must be made in situ to record the intensity of transmitted sunlight and bioluminescence.

Kampa and Boden (8) also found that throughout most of the day organisms in the layer were producing light of the same mean intensity as the isolume which they appeared to follow. Clarke (5) suggested that since the photophores of most mesopelagic animals shine downwards, luminescence may provide sound scattering organisms with a counter-shading mechanism to render their silhouette less visible to preditors below.

METHODS

To test the photodynamic role of light and bioluminescence in the migration of potential sound scattering organisms, a vertical migration tank was constructed using a plexiglass tube six feet high and one foot in diameter (Fig. 1). A square plexiglass tank was constructed around the circular tank to provide temperature control and eliminate the optical distortion caused by the lense effect of the cylinder. Tap water was pumped from a constant temperature water bath into this outside tank and circulated, by means of an overflow tube, back into the water bath. The bottom of the vertical migration tank was also made of plexiglass to allow illumination of the water column from beneath.

The test organism used was a species of estuarine mysid collected from the Patuxent River with help from the Hallowing Point Field Reserve Station at Hallowing Point, Md. These organisms are closely related to euphausiids and similar in size. In the river they migrate to the surface at night and remain near the bottom throughout the day.

Water was collected from the Chesapeake Bay at the mouth of the Severn River, filtered through a 0.8 micron filter, and transferred to the circular tank until a water column 68 inches high was obtained. Temperature and oxygen were monitored throughout the experiments using a Yellow Springs Oxygen probe, and no gradients were observed. For experiments I and II, temperature in the column was maintained at 9°C. Further improvements in the system allowed lowering the column temperature to 5°C for experiments III, IV and V. Total oxygen content decreased slowly, but evenly, throughout the column as the experiments progressed. An aireator was placed in the tank twice to renew the depleted oxygen supply. The pH of the water in the column was measured and found to have changed from 7.96 to 7.78 from the start to the completion of all experiments.

Vertical distribution of the mysids was recorded using two 35 mm cameras mounted in front of the tank. One camera monitored the top half of the column, and the other monitored the bottom. Shutters were opened on the cameras in a darkened room, and an electronic flash was fired upward from the bottom of the tank (Fig. 2). Visual observations indicated that there was no migratory reaction in response to the electronic flash. The tank was marked off in five-inch intervals so that the number of organisms in each interval could be determined from the photographs and represented graphically.

Surface irradiation from the sun was simulated by suspending a 120 volt, 50 watt incandescent bulb over the tank, and intensity was controlled by means of a variable voltage transformer. Fiber optics were used to construct a simulated bioluminescent source. A bundle of 64 fiber optic light guides was spread out and mounted in a circular plexiglass plate (Fig. 3). The other end of the bundle was mounted in front of a collimated light source. A narrow band pass filter allowed maximum transmission at a wavelength in the same range as bioluminescent light, 485 nm. The flashing effect was created by mounting a slotted disk powered by an electric motor between the light source and the fiber optic bundle. At 0.5 second intervals the entire field of fiber optic light guides flashed on and off. The collimated light, motor, disk, and filter were enclosed in a light proof box (Fig. 4), and the entire unit could be placed on top of the tank so that the simulated luminescent field was under the surface of the water (Fig. 1).

RESULTS

Table 1 lists the data as it was recorded chronologically for the sequence of experiments and gives a digitized indication of the decreasing population distribution. The results of each experiment are plotted in separate figures on co-ordinates of depth vs. time. The distribution at each particular instant of time is given as the number of organisms in a given five-inch interval.

A population of 280 mysids was transferred to the vertical migration tank at 1400 on 14 March and kept in the dark to preserve its phototactic response. Experiment I monitored the distribution of mysids throughout a 24-hour period of darkness beginning 0600, 15 March. The population was photographed at approximately six-hour intervals thereafter. Results are represented graphically in Figure 5. The first distribution indicates that 208 mysids were countable from the surface to a depth of 67 inches. This population was denoted the "active population". Mysids in the interval from 67 to 68 inches were considered to be directly on the bottom of the tank.

Throughout the day some of the organisms migrated downward and some settled on the bottom of the tank. By 2300 that night only 79% of the original "active population" was in the water column. During the night, however, there was an upward migratory trend, and the distribution the next morning indicates that the mysids were more evenly dispersed throughout the column at this time than at any other time of the day.

In experiment II (Fig. 6) organisms were fed phytoplankton initially and then exposed to approximately 12-hour periods of light and 12 hours of darkness over a 48-hour period, simulating the day-night cycle. At the beginning of the experiment, 173 mysids were in the water column. This population was taken to be 100% of the "active population" for experiment II. The light irradiating the surface was turned on, and the variable voltage transformer set at 100 volts. Distributions during the first light cycle showed a concentration at the surface and a reduced population throughout the rest of the column. One day later during the second light cycle, records indicated a reduction in the mysid population at the surface and throughout the water column.

Before experiment III was commenced over a week later, the population was observed visually and found to be greatly depleted. Mysids appeared to be feeding on 30 or more dead that had settled to the bottom of the tank; thus, those organisms below the 65-inch interval were no longer considered as part of the active population.

A simulated luminescent source was mounted at the top of the tank and activated at 1330 marking the start of experiment III (Fig. 7). The population distribution was then photographed at 15-minute intervals for 45 minutes and again after nine hours of exposure. Results show an upward migratory trend, indicating a positive phototrophism for the artificial bioluminescent light.

Experiment IV was designed to record the instantaneous response of the population to variations in light intensity at the surface. Visual observations indicated that as surface irradiation was increased, the population immediately migrated downward. Decreasing the intensity resulted in an immediate upward migration, and when the intensity was held constant the population remained fairly stationary. For experiment IV (Fig. 8), the distribution was recorded, and the surface irradiance increased by increasing the variable voltage transformer setting from 30 to 100 volts at the rate of one volt per second. After recording the mysid distribution, the transformer setting was immediately decreased from 100 to 30 volts at 2/3 volt per second and the distribution recorded again. This cycle was repeated both increasing and decreasing the transformer setting at the rate of 1/3 volt per second. In Figure 8 the population median line indicates that point above which 15 mysids were present in the water column. Migration can easily be seen by noting the change in the median point for the original population.

In the final experiment, the simulated luminescent source was mounted at the top of the vertical migration tank, and the incandescent bulb, controlled by the variable voltage transformer, was mounted below the tank. For the first part of experiment V (Fig. 9) the luminescent source was off. The variable voltage transformer setting was increased from 30 to 100 volts at 1/3 volt per second then decreased at the same rate back to 30 volts. Distributions were recorded prior to each intensity change and after the final change was made. For the second part of the experiment, the luminescent source was activated, and the same intensity changes were performed with the variable light source under the tank; distributions were also recorded as before. The final distribution in Figure 9 resulted after five minutes of exposure to the luminescent source while the variable voltage transformer setting was maintained at 30 volts. Only the top of the distribution was recorded due to a malfunction in the lower camera.

DISCUSSION

The downward migratory trend during the day and evening and the upward trend from 0000 to 0600 (experiment I) suggest that the mysid population follows an inherent migratory cycle even when exposed to continued darkness over a 24-hour period. The similarity between the graphical distribution at 0745, 16 March (Fig. 5) and 0800, 17 March at the start of experiment II (Fig. 6) reinforces this idea. Apparently the same inherent migratory cycle was followed in the time interval between the end of experiment I and the start of experiment II, also a 24-hour period of continued darkness.

The results of experiment II (Fig. 6) suggest that the response to feeding is more important than exposure to a constant intensity light source. After food was introduced, the concentration of organisms near the surface increased, while the population in the center of the column decreased. This result suggests that organisms near the food rich surface layer migrated upward despite exposure to strong light intensity, while those farther removed from the surface migrated downward to escape the intensity of the constant surface irradiation. Distributions recorded the following day, after the food had been depleted, support this conclusion, since there is no longer a large concentration of mysids near the surface, and population is reduced throughout the upper portion of the water column.

A photopositive response to the simulated bioluminescent source used in experiment III is seen in Figure 7. Measurable vertical migration resulted when the population was exposed to the luminescent source for short 15 minute intervals. An upward migratory trend is also indicated in response to constant exposure during the afternoon and evening. It should be remembered from the data of experiment I that if the mysids had been left in total darkness during this same time interval, their suspected behavior pattern would have predicted a downward settling of the population.

Figure 8 illustrates the effect of changing light intensity on the vertical migration of the mysid population (experiment IV). The response of the population to a change of intensity is evident from the rapid shift in the depth of the population median. The first intensity increase made at 1 volt/second shifted the median downward 15 inches in 70 seconds. Changing the intensity at a slower rate, 1/3 volt/second, gave the organisms longer to respond. Thus, an intensity increase of the same magnitude made at this slower rate resulted in a 30-inch downward shift in the population median in 210 seconds. Decreasing the intensity at 1/3 volt/second shifted the median point upward the same distance. Data of this experiment support the theory that sonic scattering layer migration results from the response of marine organisms to a relative change in surface irradiance.

Experiment V (Fig. 9) combined the effect of varying light intensity and luminescence. During the first part of the experiment, light intensity irradiating the bottom of the tank was increased and decreased with very little response by the mysids. This may be explained by the fact that the population was very depleted, and feeding may have been taking place on the dead at the bottom of the tank; or that the light sensitive organs of the mysids are so located as to preclude a response to light changes incident from beneath them. However, when the simulated luminescent source was activated, a marked upward migration resulted. As light intensity from beneath was decreased the population responded by migrating downward. This would suggest that the mysids are apparently sensitive to ambient light changes provided from below, and that an interaction exists between migration due to the effect of changing ambient light intensity and migration in response to artificial luminescence. While the variable intensity light was held constant and the simulated luminescent source remained on during the last five minutes of experiment V, the mysids responded photopositively to the artificial bioluminescent flashing.

The observations made in this sequence of experiments, conducted with a decreasing population of estuarine mysids, are by no means conclusive. In the absence of simultaneous control experiments, numerous repetitions should be performed for each experiment, and the data should be tested for statistical significance. However, these observations, combined with a review of the literature, do suggest that bioluminescence may provide a contributory impetus for diurnal vertical migration.

If it is assumed that bioluminescence acts as a lure to predators, and that changing surface irradiance exerts an important control on sound scattering organisms, then a model can be suggested to represent the parameters controlling scattering layer migration.

Food chain organisms associated with sonic scattering layers are the luminescent myctophids and euphausiids. Both of these prey on smaller luminescent organisms, myctophids on euphausiids and euphausiids on dinoflagellates. As preditors, they are attracted to the bioluminescence of their prey, but as prey the struggle for self preservation has led them to seek contrast conditions in which they can camouflage their own luminescence. Changing surface irradiation results in changing contrast conditions (dC_{SI}/dt). The organisms may tend to migrate, in response to changing surface irradiation, along isocontrast lines where bioluminescence is camouflaged (dC_{BG}/dt). Response to the luminescent lure of their respective prey would occur when contrast conditions were such that the intensity of the bioluminescent flash was greater than the intensity

intensity of the ambient light level (dC_{BL}/dt).

In terms of these parameters, the depth of a scattering layer with respect to time (dZ_{SL}/dt) may be expressed by the following model:

$$dZ_{SL}/dt = f(dC_{SI}/dt,\ dC_{BC}/dt,\ dC_{BL}/dt)$$

Each variable in the function must be considered relative to the conditions present in a particular scattering layer. For example, food for euphausiids, i.e., populations of luminescent dinoflagellates, may or may not be found at scattering layer depths. The model then suggests that changing surface irradiation stimulates euphausiid migration because of their phototactic response, or it stimulates them to migrate along isocontrast lines to camouflage their own luminescence. On the other hand, since euphausiids are usually found in the scattering layer, myctophids may be influenced to migrate more in response to the luminescent lure of their prey, made visible by changing contrast conditions, than directly in response to changing surface irradiation.

Consider a case where myctophids, euphausiids, and dinoflagellates are in the scattering layer before sunset. As surface irradiation decreases the luminescence of dinoflagellates is visible above the euphausiids, and the luminescence of euphausiids can be seen by myctophids below. Migrating upward, the euphausiids attempt to maintain a position where they can camouflage their own luminescence and still see the luminescence of dinoflagellates above them. Subject to the same cycle, the myctophids follow suit and migrate toward the surface.

Clearly, a better understanding of the role bioluminescence may play in migration can have useful applications. Kampa and Boden (8) have already shown bioluminescence to be coincident with these zones of sonic reverberation. Their measurements, made with a photomultiplier tube, indicate that luminescence increased at scattering layer depths. Therefore, from a military point of view, submarines may be able to use such measurements as a passive indication of layer depth and scattering strength. During World War II, some submarines took advantage of the layer as a shield against sonar detection at night when biological populations were concentrated near the surface. Measurements of luminescent intensity may extend the usefulness of these layers as an operational tool to daytime depths as well.

SUMMARY

Light in the sea may result from surface irradiation and from bioluminescence. The transmission of surface light can be calculated if the transparency of the water is known. Calculations cannot, however, account for light produced by bioluminescence. Therefore, in future scattering layer research, light intensities should be measured in situ to determine the actual change of intensity with respect to depth.

Feeding, bioluminescence, and changing surface irradiation are all important parameters that may affect the vertical migration of sound scattering organisms. Bioluminescence of prey may act as a lure to preditor organisms. However, the preditors are themselves often luminescent and are prey for larger animals. Thus, they may tend to migrate along isocontrast lines where bioluminescence is camouflaged. Response to the luminescent lure of their respective prey would occur when contrast conditions are such that the intensity of the bioluminescent flash was greater than the intensity of the ambient light level.

From a military point of view, a better understanding of the role bioluminescence plays in vertical migration may enable submarines to passively detect and evaluate sound scattering layers as a potential shield against active sonar detection.

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Table 1. Chronological Sequence of Experiments and Digitized Representation of Data

	EXPERIMENT I					II					III				IV					V					
	Darkness					Light	Dark		Light		Bioluminescence				Surface Irradiance					Bioluminescence					
																				off	off	off	on	on	on
Depth (inches)	15 March 0600	1200	1800	2300	16 March 0745	17 March 0800	1315	1900	18 March 1400	1900	27 March 1345	1400	1415	2315	28 March 0745	Intensity Increase	Decrease	Increase	Decrease	29 March 1430	Intensity Increase	Decrease	Increase	Decrease	Constant
0	43	37	26	19	25	16	19	18	5	6			2	2	2		1	2			1				
10	15	17	7	4	10	6	9	8	2	2		1		1	1	1	1		2				1		1
15	13	10	3	2	6	5	5	6	2	1				1		1	2	2	3	1					
20	7	8	6	11	6	3	2	5	2	2	1			1	2	2	3	1	5					1	1
25	8	6	5	6	6	5	3	2	4	2	1	1	1	1	5	2	5		2	1		1	1		1
30	7	8	5	6	11	5	2	3	2	2	1	2	3	2	2	2	4	2	3				2	2	1
35	7	12	8	8	13	5	4	2	3	2	1	3	2	1	3	2	3	2	2	1			1	2	1
40	4	6	7	6	11	6	4	1	1	2	2	5		2	1	2	1	1	3		1		3		-
45	10	11	7	11	10	6	1	1	4	2	1	1	2	2	3	2	2	2	1	1				2	-
50	19	15	9	5	8	4	4	3	5	1	2		1	3		2	2	1		1		2	2		-
55	27	17	17	13	10	6	4	3	3	3	2		4	1	1	1	1	1		3	2	1	2	2	-
60	19	11	21	18	14	6	4	4	6	2	3	1	2	2	4	1	2	3	1	3	3	2	2	1	-
65	18	22	25	28	22	10	6	8	8	7	2	4	4	3	6	3	3	4	4	6	5	4	2	5	-

Bottom Irradiance

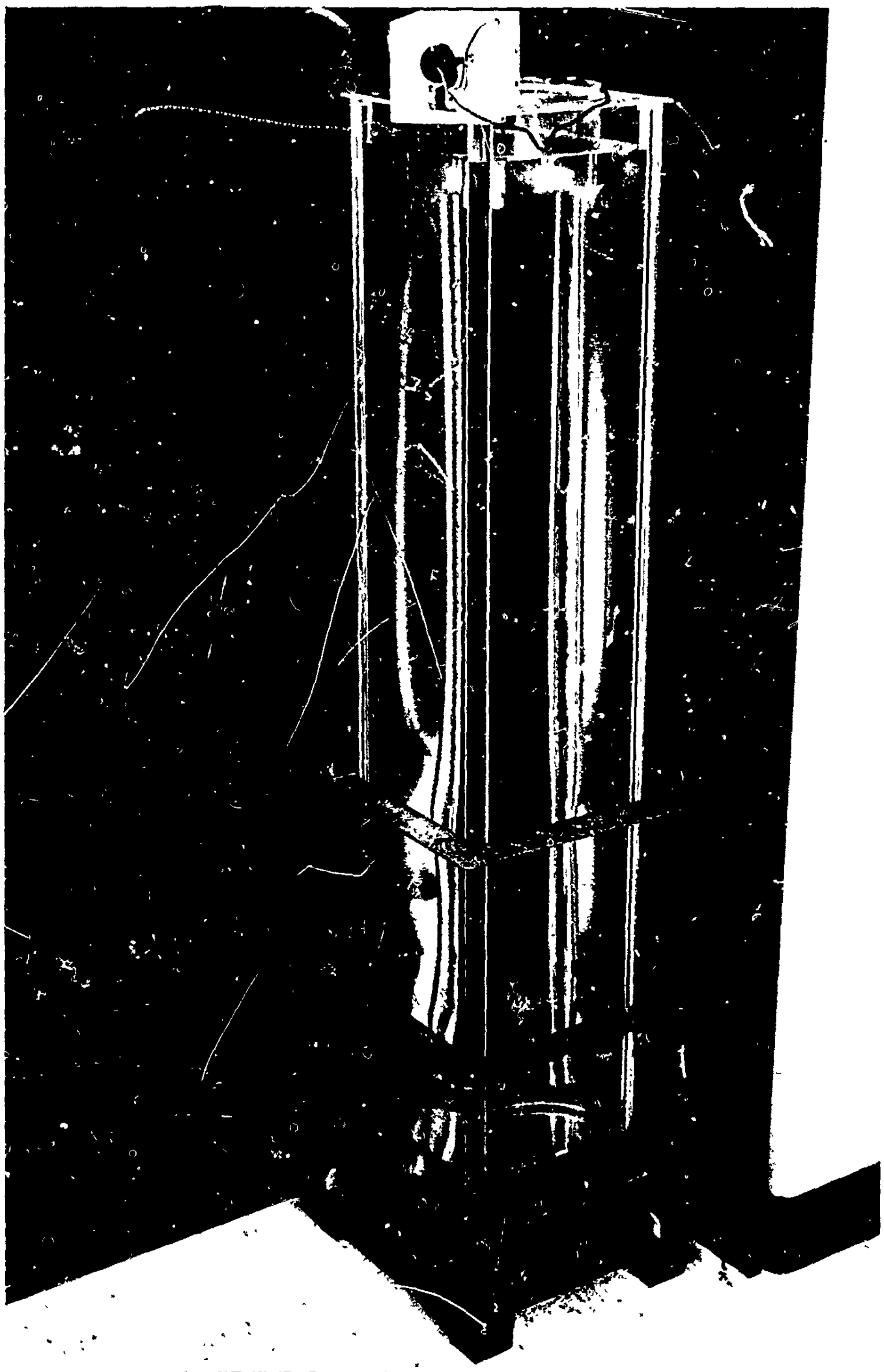

Figure 1. Vertical migration tank with simulated bioluminescent light source mounted at the surface.

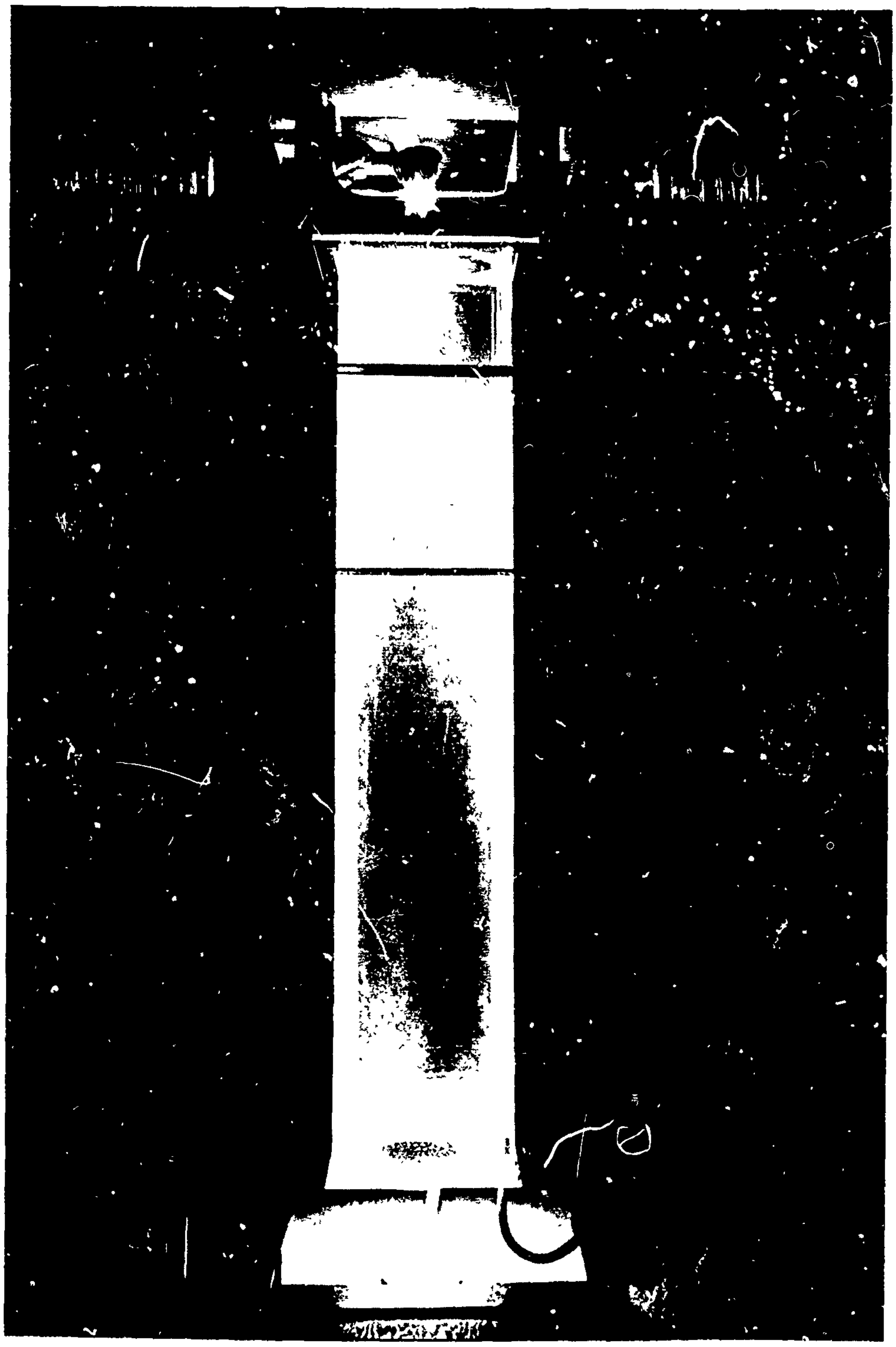

Figure 2. Vertical migration tank illuminated by electronic flash from below. The incandescent light source used for surface irradiation is visible above the tank.

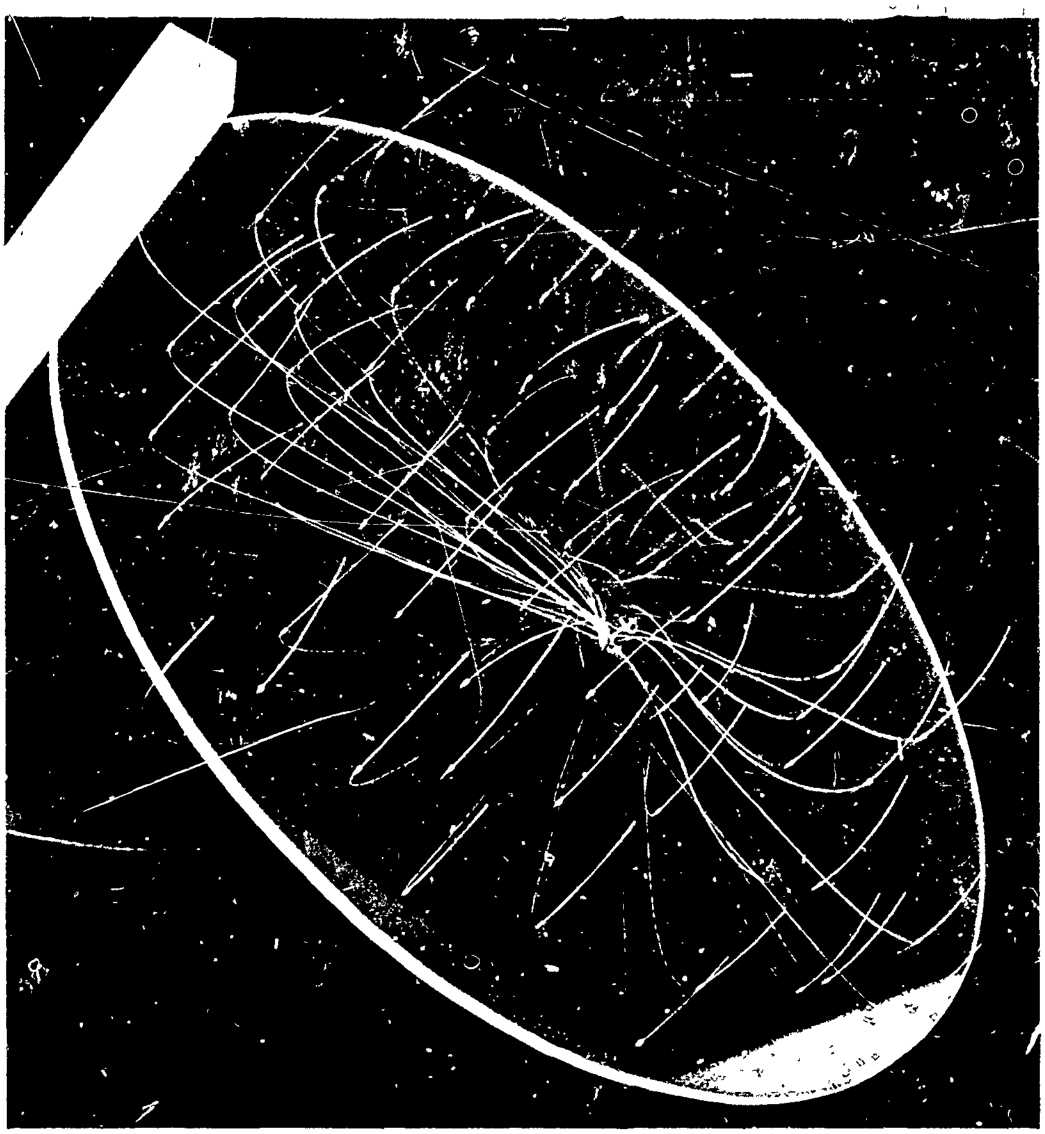

Figure 3. Simulated bioluminescent source consisting of 64 fiber optic light guides mounted individually in a plexiglass plate.

Figure 4. Simulated bioluminescence is produced by filtering (narrow band pass, 485nm maximum transmission) light from the collimated source. A slotted rotating disk causes the fiber optics light guides to flash at 0.5 second intervals.

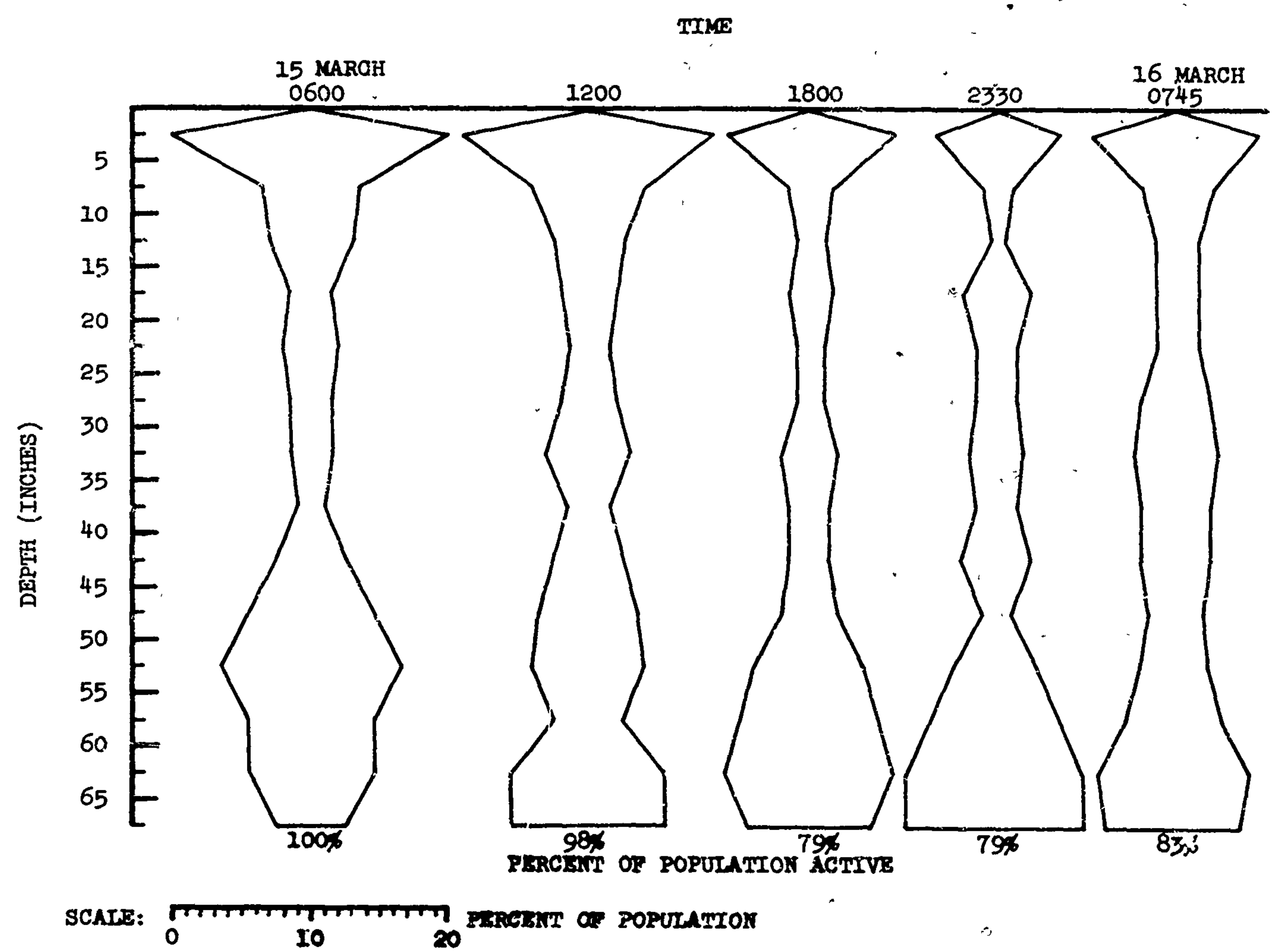

Figure 5. Experiment I, 24-hour period of darkness.

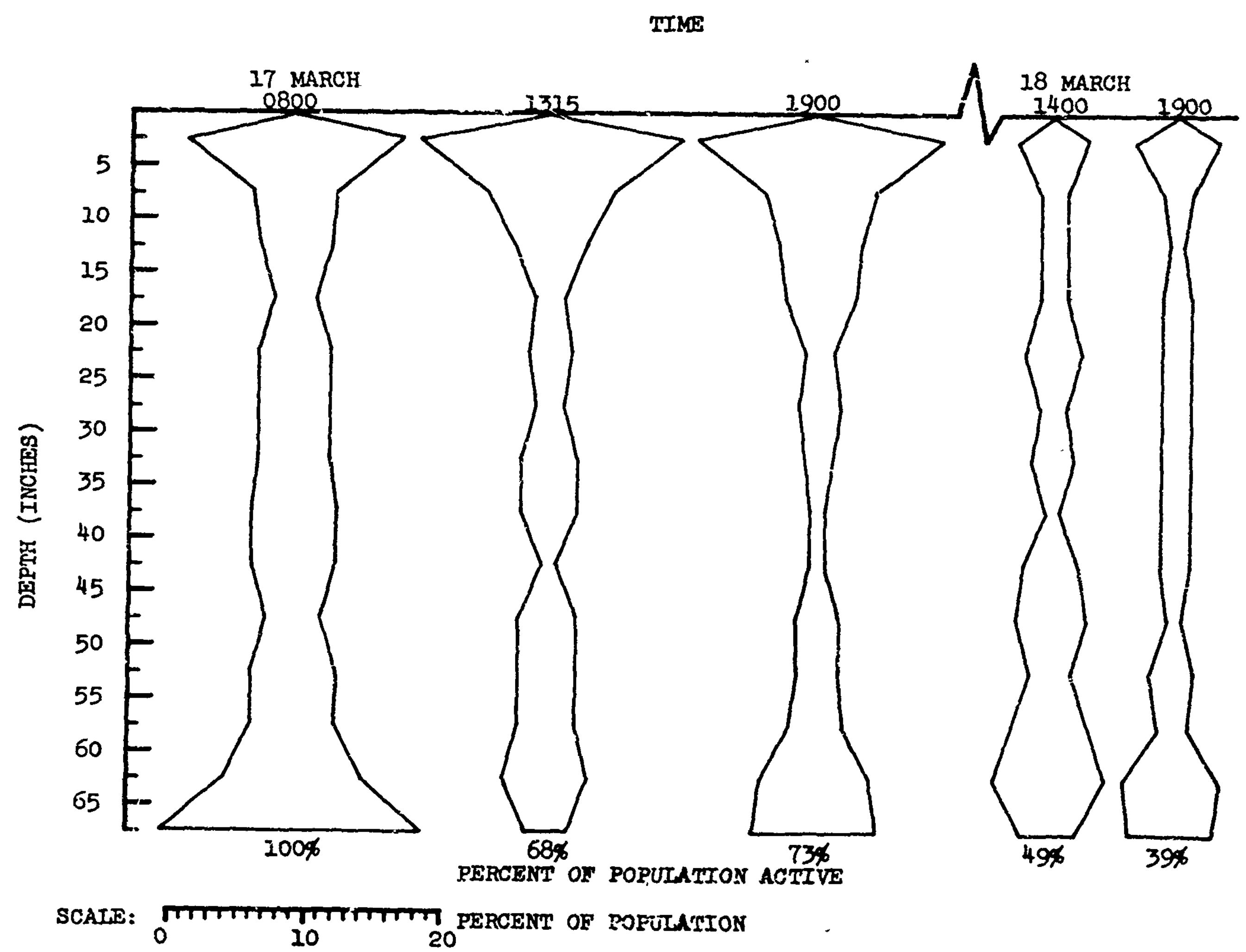

Figure 6. Experiment II. Food induced at 0805. Surface irradiated with constant light from 0815 to 1905, 17 March; Surface dark from 1905 to 0800; Surface irradiated from 0800 to 1905, 18 March.

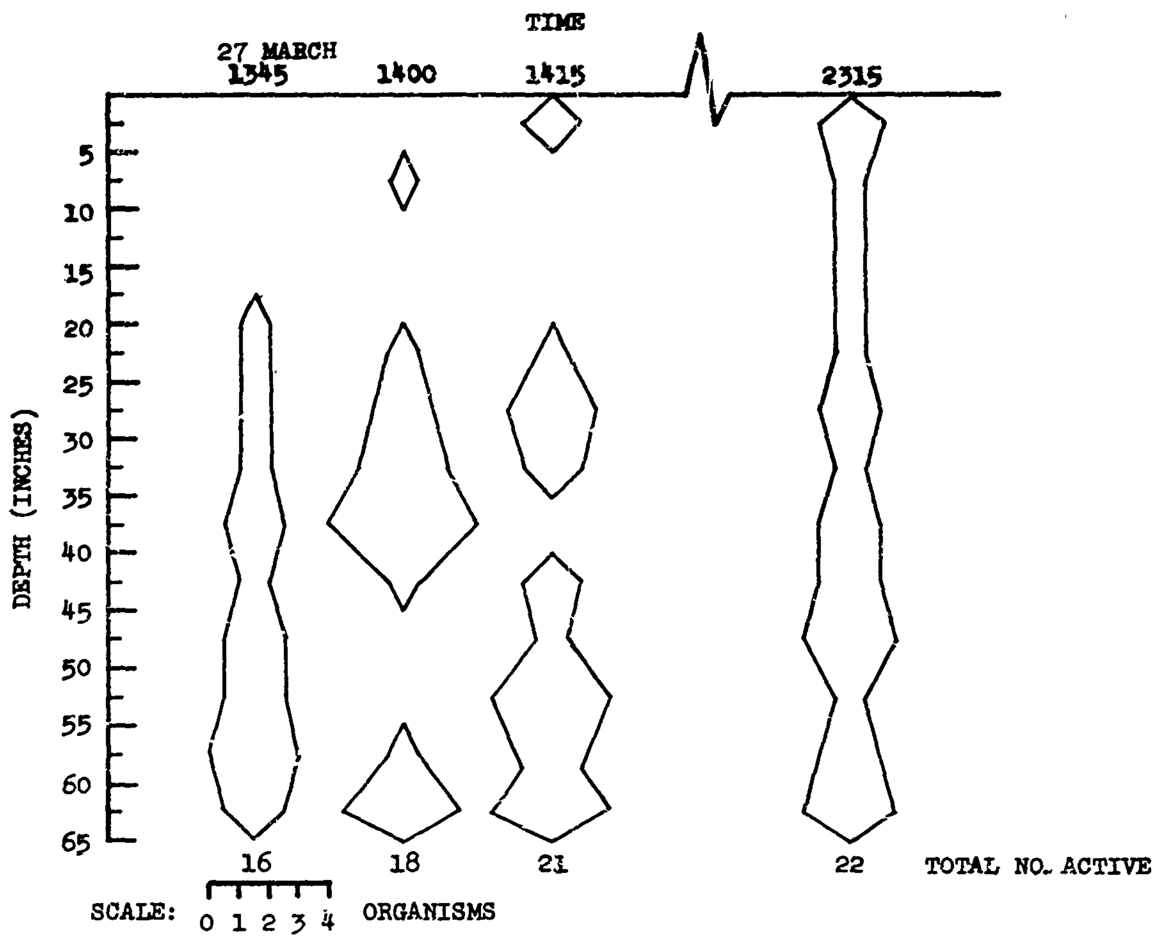

Figure 7. Experiment III. Constant exposure to simulated bioluminescence.

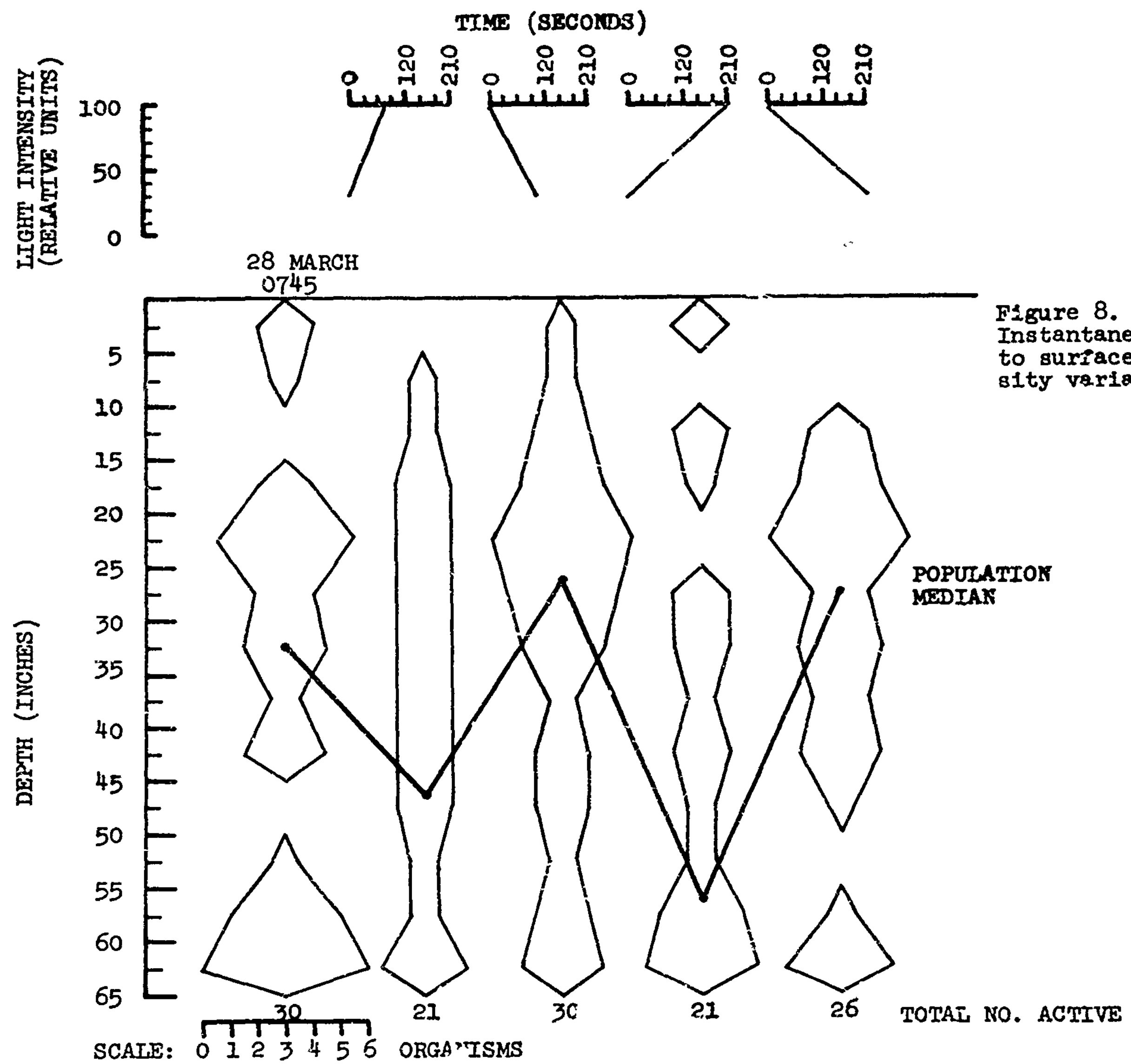

Figure 8. Experiment IV. Instantaneous response to surface light intensity variation.

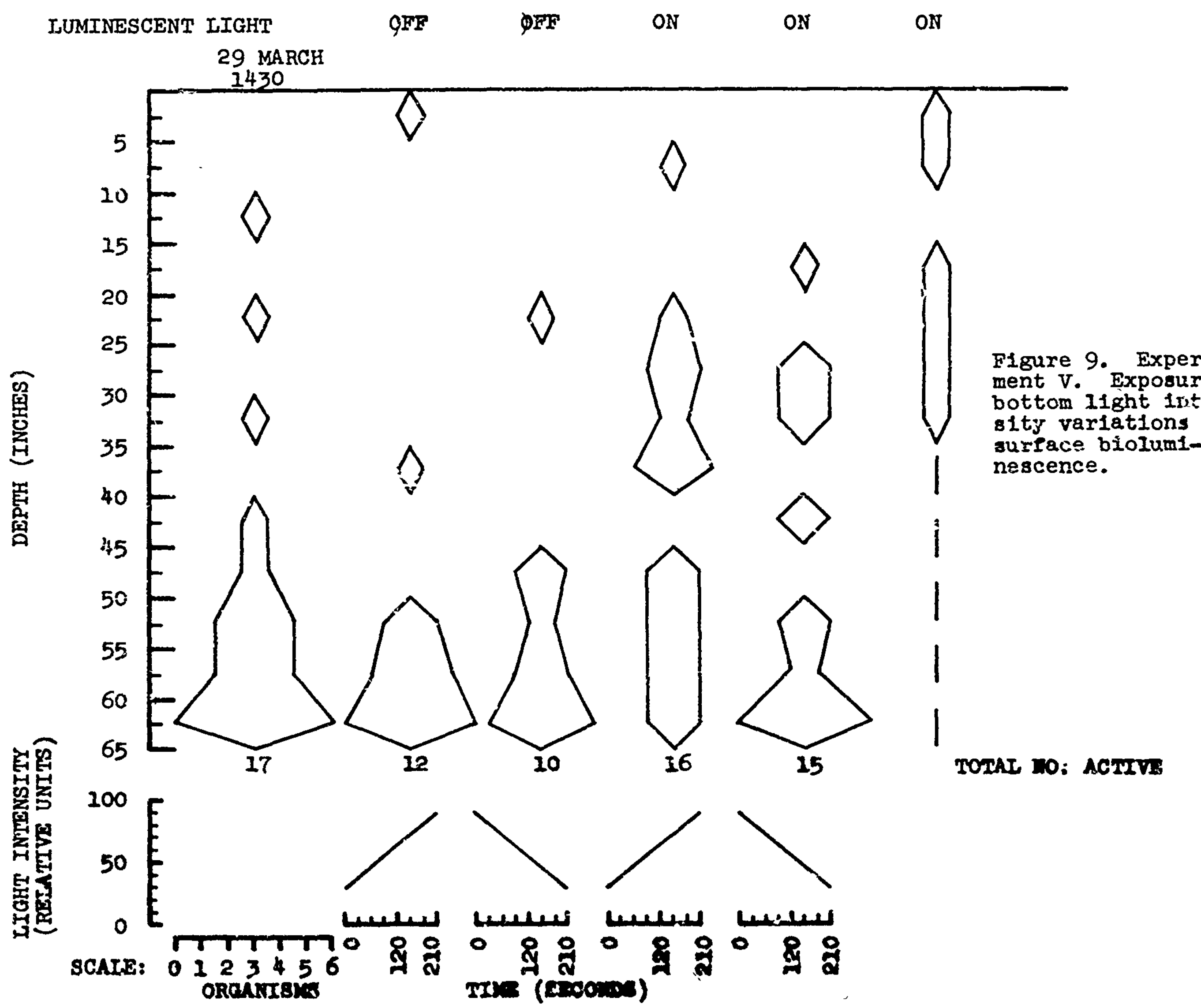

Figure 9. Experiment V. Exposure to bottom light intensity variations vs. surface bioluminescence.

RADIATION-INDUCED ACOUSTIC CAVITATION IN A SCINTILLATING LIQUID

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ABSTRACT

A study of radiation induced cavitation has been conducted in a series of five resonators. The intent of this study was to establish a time correlation between the incidence of radiation and the subsequent cavitation event. To accomplish this a scintillating liquid was enclosed in a cavitation cell and subjected to three types of radiation, neutrons, alpha particles, and fission products. The radiation was intended to produce a scintillation event and a cavitation event, and a time correlation was to be established between the two. To date the results have been essentially inconclusive. Equipment problems have been severely hampering. Satisfactory results should be obtainable, and the study should be continued.

BACKGROUND

The study of radiation-induced acoustic cavitation is a relatively new field, which opened with Lieberman's' (1) work with acetone and pentane in 1959. One of the reports responsible for my pursuit of this subject was that of Sette and Wanderleigh (2). In this paper Sette discussed the effects of cosmic rays on liquid samples in an acoustic field. He found that shielded samples did require a higher threshold for acoustic cavitation and theorized that radiation reduced the cavitation threshold. Barger's work (3) supported this theory. It was also in his 1962 work that Sette predicted that cavitation nuclei produced by radiation would have a half-life of several minutes or more. Then in 1967, Greenspan reported that he had discovered "no appreciable induction or decay time" for the onset of acoustic cavitation upon incidence of radiation (4). It was my intent to study the actual time correlation here, in order to determine which of the theories was correct.

THEORY

Acoustic cavitation is a useful tool for the study of cavitation because it is readily producable in the laboratory. Basically it can be defined as the growth and subsequent collapse of a vaporous or gaseous cavity in the presence of a sound field. The nucleus for this cavitation is normally an inhomogeneity in the liquid known as a mote. Sufficient motes are removed so that cavitation will not occur on a mote at a pressure below 2T; then cavitation may be nucleated by irradiation with nuclear particles. T is the cavitation threshold. According to Sette (2), this nucleation is accomplished by the deposition of energy in localized regions by ionizing radiation. These regions are commonly referred to as "hot spots", and are considered the cavitation nuclei in radiation induced cavitation. If the acoustic pressure in the liquid is above threshold, a small bubble will form and will go through a series of expansions and contractions until the radius is larger than the critical radius. Then the bubble will collapse violently, producing the associated noise or light as described by Flynn (5).

Since radiation can produce this acoustic cavitation under certain conditions and since ionizing radiation also can produce scintillation, tying the two together is a relatively simple process. It appeared to be an ideal way to study the time correlation between the incidence of the radiation and the subsequent cavitation event. The study would provide a solution to the question of whether or not radiation induced nuclei have a measurable lifetime.

The first problem of major importance was the design of a resonator suitably efficient for the purpose of the experiment. The work of Greenspan and Tschiegg (4) suggested the use of a cylindrical transducer. A PZT-4 barium titanate transducer, O.D. 3 inches, I.D. 2.62 inches, and length 3 inches was selected. Outer and inner surfaces were silvered by the manufacturer. A brass ring .5 inches thick was cemented to the upper end of the cylinder with Marinetex, a commercial epoxy, and a ring .38 inches in diameter was cemented to the lower end of the cylinder. The rings served several purposes. First they were used to establish electrical contact, the upper ring being connected electrically to the inner ground surface, and the lower ring being connected to the outer drive surface. A groove was cut in the upper ring for placement of an O-ring. Threads were cut on the outer surface of the upper ring to provide for a screw down lid for the cell. The lid was simply another brass ring, .25 inches thick, threaded on the inner surface. Electrical contact between the lower brass ring and the outer cylinder surface was established with a conducting silver epoxy. It was also found to be necessary to remove a strip of silver from the upper protion of the outside surface in order to prevent a short circuit. Holes were drilled in the upper and lower rings to serve as entry and exit tubes. Brass-filled tubes were soldered over the holes for ease of attachment of piping to be used in the filtering system. An aluminum plate was selected for use as the lower surface due to its very small captive cross section for thermal neutrons (.24 barns). The plate was attached to the base of the transducer with RTV, silicone rubber glue. However, the aluminum proved unsatisfactory as it became readily pitted due to an electrocatalytic reaction with water. The second choice for a base was stainless steel which served its purpose very well. The capture cross-section for iron (2.62 barns) is approximately ten times that of aluminum but a compromise was necessary. Finally, a circular piece of glass, .08 inches thick was epoxied to the lid, the O-ring seal being made against the glass. Glass was necessary in order to transmit the scintillation to the photo-tube. The lid was used in order to allow the sound field to be examined with a piezoelectric pressure probe. However, due to operating problems which will be discussed later, it became necessary to abandon this design and come up with another improved design.

Another transducer of the same type used in the original cell was the basis for the new cell. However, many modifications were incorporated into the design. Two strips of silver were removed from the upper and lower portions of the exterior of the cell. The strips served another purpose as the mounting points for the cell in its horizontal position. The O-ring seal was abandoned completely due to inherent problems. A brass ring was again used at the upper end as a mounting platform for the fill tubes. The ring, however was only .1 inches in thickness rather than .5 inches as the previous ring was. Two holes were drilled in this ring and lengths of copper tubing soldered to them. Since electrical contact was to be made with the exterior surface of the cylinder rather than with the brass rings, it was necessary to establish an electrical path across the bare ends of the transducer. To accomplish this aluminum was sputtered on to these surfaces using a vacuum system. A large bell jar was evacuated to a pressure of approximately eight microns. Small strips of pure aluminum were heated on a tungsten wire and vaporized. Reaching the exposed surface of the cell, the aluminum vapor condensed producing a thin layer of aluminum suitable for conducting current. The brass ring was then epoxied to the cylinder to seal the upper end of the cylinder; a circle of stainless steel sheet was cemented to the brass ring with RTV. The thickness of the stainless steel was 12 to 75 µm. To seal the base of the transducer, glass was again required. However, in this case it's thickness was .01 inches. RTV was again the bonding material at this point. It was also deemed necessary to form a thin ridge of RTV at the outer edge of the glass in order to prevent breakage when in the upright position. It is easily noted that this new design had external mountings which were much less massive than in the previous design. The significance of this will be discussed later. Suffice it to say at this point that this design was the best of the five used. Due to a failure of the electrical contact on the aluminumized ends, it became necessary to modify the design somewhat. Four small strips of wire were soldered to the inside surface and to the outside surface to act as current paths. The brass ring was then cemented on top of these.

The third design was an externally driven cell. This design was necessary because of the ease with which water may be cavitated in it. Greenspan, in particular, mentioned external drive as ideal for use in the cavitation of water. This particular cylinder also served a purpose in the calibration of the acoustic pressure probe used. The cell itself was simply a glass cylinder six inches long, with a diameter of 1.18 inches. The drive was provided by a disc transducer, silvered on both sides, .5 inches thick and 1.5 inches in diameter. A brass disc 1 inch thick and 1.5 inches in diameter, was epoxied to the base of the transducer with silver conducting epoxy. It's purpose was to serve as a frequency shifter and to provide electrical contact. A brass ring was fitted around the lower end of the glass cylinder and the entire assembly was epoxed to the upper surface of the transducer with silver epoxy. Again electrical contact was made through the brass ring. A fill tube was soldered over a hole drilled in the brass ring. This proved to serve a rather novel purpose which will be discussed later. Finally a brass ring was epoxied to the upper end of the glass tube to prevent it from cracking.

The fourth cell utilized was a small replica of the second. The cylindrical transducer used was a PZT-4 barium titanate transducer, O.D. 2 inches, I.D. 1.62 inches, and length 2 inches. The same types of stainless steel sheet and glass were used. The only difference was in the material used for the ring. On this cell it was titanium. Electrical connection was also accomplished with thin wires soldered to the outer and inner surfaces.

The fifth resonator used was an externally driven Erlenmeyer flask, also suggested by Greenspan's work (2). The flask was a standard 250 ml Pyrex Erlenmeyer. To its base a disc transducer of the type used in the externally driven glass cylinder was epoxied. Electrical contacts were made directly to the silver surfaces of the transducer. A brass plug was epoxied inside the neck of the flask. Two holes drilled in the plug served as filling tubes. Two lengths of copper tubing were epoxied above the holes. A disc of brass 1.5 inches in diameter and .75 inches thick was epoxied to the base of the transducer to act as a frequency shifter. This resonator produced many interesting effects to be discussed later.

ELECTRONICS

A brief outline of the electronics is given below. Basically, the input side of the system consisted of an oscillator with which frequency was controlled, a power amplifier which amplified the oscillator signal and supplied power to the cell, a frequency counter, a tuning circuit, and a voltmeter measuring input voltage. The output side consisted of a phototube supplied by a high voltage power supply, a signal amplifier, and an oscilloscope.

LIQUIDS

It was necessary to find a liquid suitable for cavitation, but which at the same time was chemically inert with respect to the materials used in the resonators, and finally which could act as a solvent for the standard scintillants available. Decalin, a paint base, was originally considered due to its immediate availability. It had no chemical effect on the materials used in the resonators. Its high viscosity was a definite drawback since this could only increase its cavitation threshold. An attempt was made to find a boron compound which would readily dissolve in decalin, but none was found, so decalin was temporarily discarded as a possibility. The next liquid considered was toluene. Due to its low tensile strength, toluene is considered one of the "weak" liquids, i.e. it does not require large negative pressures to cavitate it in the presence of radiation. Therefore, it was considered ideal. Also, according to Birks (6), toluene is a standard solvent in the practice of liquid scintillation counting. It was also easily doped with trimethyl borate, a boron compound which is considered a standard doping material. It was also found later that it readily acted as a solvent for a solution of methanol and uranyl nitrate or thorium nitrate, the uranyl nitrate producing fission events and the thorium nitrate producing alpha-particles. This was the liquid used in most of the experimentation. It also had one other distinct advantage; being a very powerful solvent, it "wetted" the motes in the liquid to such a degree that it did not require extensive filtering. The only problem encountered with the toluene was its tendency to swell the RTV glue, eventually breaking the bond. It also slowly attacked the Marinetex and the silver epoxy. One of the reasons for the abandonment of the O-ring was its tendency to swell in the presence of toluene. An attempt was made to make use of the decalin by dissolving either uranyl nitrate or thorium nitrate in acetone or methanol and then to dissolve the solution in the decalin. Methanol will not dissolve in decalin, and uranyl nitrate came out of the solution with acetone when mixed with the decalin; so the attempt was unsuccessful.

Two auxiliary systems, also described in the Appendix, were necessary, a degassing system to remove dissolved air and prevent gaseous cavitation, and a filtering system to remove the motes from the liquid, preventing cavitation from occurring on these motes. Motes still present in the liquid when experimental work was performed would have rendered the results meaningless.

Work was originally performed with the first cylindrical transducer described in the appendix. The first assumption made was that if the cell would cavitate clean, degassed water under normal conditions, it should have been able to cavitate the scintillating liquids which are weaker than water in the presence of some type of irradiation. Barger's value for cavitation threshold in degassed water at an ambient pressure of 1 atmosphere is 12 bars. (3) Greenspan's value for neutron-induced cavitation with a PU-BE source and methanol is 5 bars. (4) Making the assumption that toluene's cavitation properties are similar to those of ethanol, it was logical to consider a resonator which would cavitate clean, degassed water as suitable for cavitating toluene under test conditions.

Cavitation in degassed water was found to occur readily in the (3, 0, 1) mode at a frequency of 51.9 KHz. Input voltage at threshold was 15 volts. Subsequent measurements with the acoustic pressure probe showed a (1, 0, 1) mode at 30.1 KHz. Water also cavitated easily in this mode but it was not the sharp, cracking cavitation that was present in the (3, 0, 1) mode. The cell also showed a tendency to heat up in this mode, indicating that electrical power was not being efficiently transformed into acoustical power. It was also discovered at this point that the aluminum plate was undergoing an electrocatalytic reaction and becoming pitted as a result. Aluminum oxide was formed in this reaction which effectively contaminated the liquid. The plate was replaced with stainless steel.

Preliminary experiments were conducted with a known alpha-source, Pu^{210}, to determine the response of the phototube to the experimental arrangement. With the aid of a multi-channel analyzer, it was found that the system had entirely satisfactory response to the 5.3 MEV alphas of the PU-BE source. The resolution was extremely good, the background at energies above 1.5 MEV being small.

At this point electrical contact between the brass ring and the inner surface of the transducer was broken and repairs were necessitated. In any case, after repair the Q of the system had been reduced considerably along with a shift in the resonant frequency. It now cavitated water at 52.5 KHz with an input voltage of 250 volts. The cell heated rather severely, and the epoxy started to disintegrate. The conclusion was that the system was too highly damped, requiring large amounts of power to drive it. The O-ring was obviously a highly damping fixture. The massive rings, the steel plate, and the glass plate, severely constricted the vibration. It was decided that a cell was required whose fixtures were of light construction, and whose ends were of a material which would allow as much as possible an approximation to a free-surface pressure-release boundry.

The new cell was constructed and tested. The (3, 0, 1) mode was at 50.4 KHz and cavitation in degassed water occurred with an input voltage of only nine volts. The Q of the system was measured using the tuning circuit described in the appendix and was found to be 25,000, more than sufficiently high for experimental purposes.

The uranyl nitrate had been settled upon as the ideal source of nucleating particles. It was chosen because the fission fragments, being of much higher energy, would lower the cavitation threshold considerably. It also has a relatively low fission yield (25 spontaneous fissions per gram per hour), which allowed for the viewing of each event on the oscilloscope. It was determined by comparison with the length of the alpha-particle trace produced by the 4.19 MEV alpha emitted by the uranium that the random events occurring at a rate of 2 per minute had energies of 60 MEV. These could only have been fission fragments.

The first attempt to produce the radiation induced cavitation was in the uranyl nitrate solution. No neutrons were used. The alpha particle flux per gram per second is on the order of 10^6 alphas. In the 50.4 mode with an input voltage of 40 volts, very faint pings at the rate of 30 to 40 per minute were audible. The cell was then irradiated with slow neutrons with a background of 120 fast neutrons per second entering the cell. No appreciable difference in the type of cavitation or cavitation rate was noted.

In the 2 inch transducer, cavitation of decalin with fast neutrons was attemped at 35. KHz with no success. The cell was then filled with degassed water and an attempt was made to cavitate water at 35.1 KHz, with no success, whatsoever. Gassey water produced the hissing sound characteristic of gassey cavitation. The cell was driven at maximum power with no hard cavitation resulting. The stainless steel sheet vibrated violently and eventually the inside wall of the transducer suffered severe damage due to the high amplitude wall motion. The Q of the system was measured and found to be only 450. It was concluded that this cell was not suited to the experimental work. The most logical explanation for this may be the large proportion of the surface area occupied by the fill tubes. The surface area of the 3 inch tube is over twice that of the 2 inch cell while the tubes are equal in cross-sectional area. Thus they resulted in a proportionally higher power loss for the small cell than for the large cell. This undoubtedly produced the small Q measured.

The glass cylinder produced highly contradictory results. With degassed water at an operating frequency of 52.3 KHz and an input voltage of 48 volts, a count rate of 8 counts per minute was established. Then the cell was subjected to neutron irradiation, and the count rate rather than increasing as would have been expected, decreased to 4 counts per minute. The only conclusion which could be drawn from this result was that the neutrons were not responsible for the cavitation at all. The liquid obviously contained motes which were drowning any radiation effects.

The Erlenmeyer flask produced highly significant results. Degassed toluene doped with uranyl nitrate produced good sharp cavitation at a frequency of 38.6 KHz and an input voltage of 34 volts at threshold. To determine whether or not this was indeed radiation induced cavitation, a test sample of undoped toluene filled the flask to the same level as the doped sample level. Frequency was identical and the voltage was set at 34 volts. Cavitation did not occur. The voltage was turned up at increments of 2 volts and the undoped sample began to cavitate at a threshold of 50 volts. In any case the threshold was considerably reduced by the presence of the uranyl nitrate. Thus it appeared as if radiation induced cavitation was actually occurring.

In the cylindrical transducer, hard cavitation was produced at a threshold of 20 volts and a frequency of 42.9 KHz. These events occurred at a rate of 1.5 per minute and continued until the equipment was shut down. It was noted that th cavitation events bore no immediately apparent relation in time to the scintillation flashes in the scope. In another run conducted in precisely the same manner, cavitation occurred immediately at a rate of 6 events per minute but within several minutes, cavitation ceased completely. Neutron irradiation was then commenced with the power turned down. The cell was irradiated for twenty minutes and then the power was turned up with no cavitation resulting.

DISCUSSION

The work of the project was severely hampered by equipment failures and malfunctions requiring long periods of dead time for repair and modification. The resonators in particular proved to be extremely difficult to maintain, since with each use they deteriorated to a greater extent. The epoxies and glues presented many severe problems, as they failed several times during testing. The electric field on the cell itself produced interference through the phototube which distorted the video output. The degassing and filtering system worked well, but they were of course extremely simple pieces of equipment.

The cavitation results are at best contradictory. One run readily suggests that radiation induced cavitation is occurring while the next simply implies the well known fact that liquids are strengthed by repeated cavitations and that the cavitation rate will decrease with time. The neutron irradiation produced no significant results. Neutron irradiation increased the fission rate of uranyl nitrate, but the cavitation rate with neutron irradiation remained the same as that without. And most importantly, the results were not reproducable.

CONCLUSIONS

Because of the importance of cavitation research to the Navy, and because of the necessity to conduct experimental work in the laboratory on such a phenomenon, the study of acoustic cavitation should by all means be carried on. An apparatus was developed and tested which shows significant promise of success with some refinements. The necessary liquids have been investigated and a very useful one has been discovered. All that is needed for a solution to the problem is more work. The knowledge necessary for the study has been extended and the solution is simply waiting to be found.

ACKNOWLEDGEMENTS

I wish to thank my advisor Dr. Lawrence A. Crum, for his assistance in trying to assist me in reaching a solution to the problem at hand. I also express my gratitude to Mr. Howard Tavarez, Mr. Charles Stump, and Mr. Grover Humphrey who provided me with technical assistance when it was needed.

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APPENDIX

The Tuning Circuit

The cell tuning circuit consisted of two variable capacitors connected in parallel with the cell, a clip-on Textronix current probe, a current to voltage convertor and a voltmeter. This rather ingenious set-up was described by Greenspan (4). The capacitors connected in parallel have had their leads reversed. Thus the clip-on probe senses the summation of the currents. At a frequency not a resonant frequency of the cell, the variable capacitors are tuned until the probe has its smallest possible output. The circuit is then tuned for all frequencies. At resonance the current will increase sharply due to the large inc ease in motional current. Before the use of this device a variable inductor had been used. However, it was necessary to retune the circuit each time the frequency was changed with such a system.

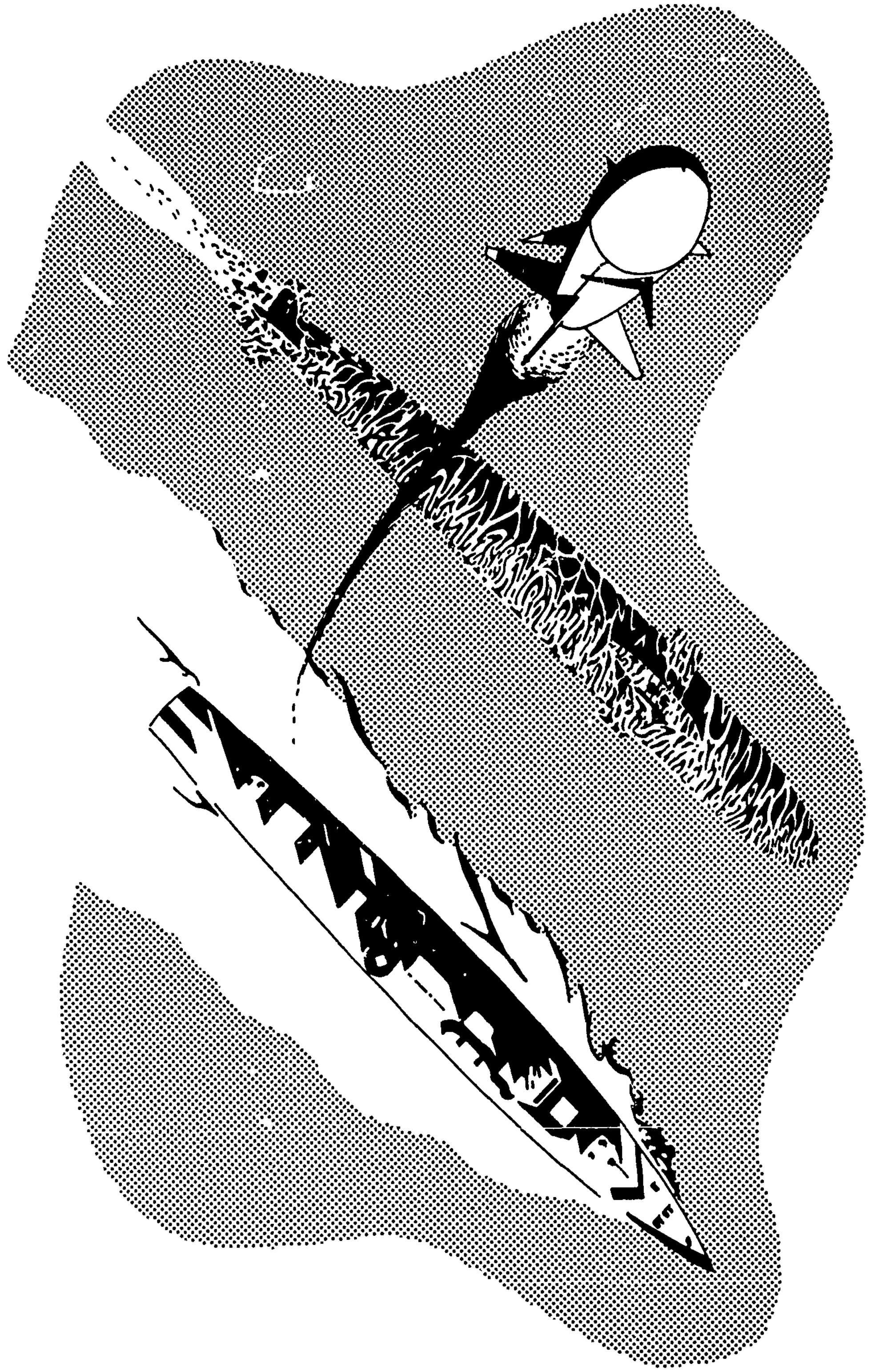
The Auxiliary System

Degassing and filtering of the test liquid wire necessary in the pursuit of meaningful experimental results. Gassey liquids will produce soft hissing cavitation, detuning the circuit, at a threshold well below the threshold for hard cavitation. Filtering of the liquid was necessary to remove any contaminated motes. The first attempt was aimed toward producing a closed circulatory and degassing system. A pump, reservoir, and the cell were connected in series. The reservoir was sealed and could be pumped down with a water aspirator. A valve was installed which allowed argon to fill the vacuum over the liquid in the reservoir. Its purpose was to enhance the scintillation properties of the system (6). Two main effects were noted which rendered the system unusable. First, when degassing, the entire system became laced with air bubbles which in turn formed larger air pockets. Until a system could be devised to remove bubbles in the line and cell, the system was essentially useless. The air bubbles themselves caused further problems in that they produced air locks in the pump. Essentially what was done after this was to divorce the degassing and filtering system from the cell. The liquid sample was first filtered, then degassed, and finally poured into the cell. This system of course has inherent problems, in particular, the necessity to pour the liquid undoubtedly led to a risk of contamination.

The Glass Cylinder

Liquid height is of prime importance in the proper functioning of the glass cylinder because the resonant frequency of the transducer-brass disc combination is the resonant frequency of the system. Therefore, the water height must be the proper number of wavelengths along the tube. Using the current probe a simple method was devised to find the most efficient water height of the system. The system was tuned with the variable capacitors. Then the water level was lowered drop by drop by cracking the outlet valve on the exit tube. At the point at which the current probe sensed the largest current, the valve was shut. This water level was the proper operational level for the system.

Fleet Oceanographic Problems



MATTERS OF CONCERN TO FLEET OPERATIONS AND THE ROLE OF THE OCEANOGRAPHER

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ABSTRACT

Oceanographer, in cooperation with tactician, must furnish understandable products immediately applicable in the operational sense. It is essential that the R & D cycle begin with the operating forces, work with them in progress, maintain the operational viewpoint, insure Fleet gets and learns to understand the application of the material. Specific products such as catalogued source level and signature of possible contacts; statistical statements of effects of reverberation interference and its occurrence, characters of oceanic watermasses (size, number, location,) and effect on sonic transmission presented in terms of tactical result; and, finally, development of a program, is required to instill in the operating forces the necessary grasp of effect on tactical success so that forces may understand the limitations imposed by the environment.

There exists in the Naval world today a vast amount of information, dearly bought over a long period of time, which is labelled as "Oceanographic Information." This should be making a significant contribution to Naval Operations by permitting the operating forces to consider the effect of the environment on their operations. Yet, we are in conference here today asking ourselves questions about what do we need to know from the oceanographer to help us to exploit the ocean medium. The answer as seen at Headquarters, Commander Antisubmarine Warfare Force, U.S. Atlantic Fleet is not simply deciding what the Fleet should be asking for, i.e., what data can be collected and run in on the operational net to help solve operational problems. It is more fundamental than that. A basic understanding remains to be developed of both the ocean and its processes and its effects on operations. This is not to say that progress has not been made in the past: it has. We must recognize the potential value of stores of knowledge held by the oceanographer and by the operational forces. We must now contend with how to get the information in useful form to the operating force requiring environmental support information. The basic problem is the uncertainty of the user as to how oceanographic information can be made useful to him, and uncertainty on the part of the holder of oceanographic information as to how to render operationally useful applications.

It should be axiomatic that both sides have a basically correct picture of the ocean. We can agree, if we both should observe it together from a ship, that the sea surface has waves so many feet high and that we sense the ship motion being affected by these in a specific way. This agreement is easily reached, but it also is, unfortunately, about the limit of our agreement.

As we look down into the ocean, and try to divine the effect of other parameters upon our operations, we learn how much remains to be done. We have measured and spoken of the ocean as a sonic medium, particularly in the ASW problem. We have attempted to describe the ocean thermally, and by inference sonically, by examining its temperature at the surface, at different depths, and then providing the man at sea with this information. As a first step this was helpful if the assumptions and rather severe limitations of this approach are understood. The operational follow-up to the thermal structure information is where the greatest improvement was to be made. In other words, the user must know how to apply this information. The operating forces need a knowledge of the general appearance of the ocean as a sonic medium and the general worth of different combinations of forces as conditions change over an operating area or period of time. This can be done by providing:

a. Statistics of submarine detectability by active and passive sonars.

b. Evaluation of factors causing variations in detectability.

c. Defining of detectability levels in the oceans, and

d. Providing techniques for converting present day forecasts and climatologies to figures of detectability and force effectiveness.

In sum, an understanding of the sonic structure of the ocean, as read by thermal instruments, is urgently required. We must know what the true oceanic variability is. With this understood, you can provide information on the effect of this variability on sound path. This understanding of variability is considered the primary need for improvement of environmental support to ASW forces. From this you can furnish reliable statistics of detectability for different areas and forces.

Identification of a source of sound in the sea, whether it is sub or non-sub, friendly or hostile, depends on the ability to recognize the frequencies and source level of that sound as being unique in some way. The independent unit on station cannot do this unless he is equipped with some sort of index of source level and frequency guide to foreign ships of war. Considering the need for ability to quickly determine hostility of craft, the user needs a well-constructed key to provide him this information. It must be easy to use, fast to give results, and useful in ships and aircraft. This is considered a second most fertile work area to improve ASW capability.

Much has been written and said about reverberation effects in the sonic detection problem in both shallow and deep water. We are not complaining that too little has been done. We are well aware of the extensive completed studies and of numerous published reports. We are concerned that the fleet does not yet have a quickly understandable, readily accessible, useful document which will apprise them of the probable effect of reverberation level on their active sonar systems. It should be relatively easy to provide a statistical statement by area, time, and sea state, of the effect of volume, surface, and bottom reverberation on detection systems. Such a handy reference type of information will answer this third important problem.

Much research has been devoted to major oceanic fronts such as the north wall of the Gulf Stream. Exercise analyses show that some similar phenomena of lesser intensity must also exist. Whether these are convective cell boundaries, weak fronts, or whatever, we need to know their occurrence, size, statistical description, relation to variations in detectability, and possibilities for their tactical exploitation. This, then, is the fourth basic oceanographic problem.

Once an understanding of ocean structure and its variability is gained, there remains the task of tactical exploitation. The requirement is for some sort of tactical indices and tactical instructions which will relate environmental condition to tactical operations. These will not be portrayals of the environment; they will be tactical documents which will give the screening units their probability of success against the submarine, will alert the carrier commander to his actual vulnerability, and give the aircraft commander his probability of success. Force Commanders in their operational control centers will be apprised of how capable forces are in relation to the submarine threat, what assignment of resources, ships and aircraft, will yield a given level of success within the area and time of the operation. With a broad picture, the Force Commander can estimate his ability to accomplish his mission. So, also, can his subordinates estimate their capabilities as greater detail is provided. The "Sense of the Environment" is what the operator really needs, not an education in academic oceanography. It is the oceans influence which is important to him, not oceanography itself. Preliminary thoughts on how to improve the employment of the environment show that our present understanding is inadequate. This, the fifth problem, looms as the most important and least worked one cited so far.

The basic instrument for progress in using new ideas is the research and development cycle. This must be the point of strength and the beginning for any progress. Since R and D is based upon "requirements" they must be the first consideration. The Fleet now has formal input in the annual submission of "Oceanographic Requirements". This plan is excellent and is the first step in the right direction. The Fleet, however, often does not understand the basic problem well enough or has misplaced its faith in oceanography so that the result is submission of the wrong requirement to solve the right problem. The Fleet should be brought into the R & D picture in a more fundamental way and at an earlier stage by consultation when the GOR (General Operational Requirement) and the SOR (Specific Operational Requirement) are written. Under our present system, it is possible for GORs and SORs to be conceived, written, and placed for fulfillment without direct consultation with active Fleet workers. While the concept of the "Operational" side of Washington offices writing requirements for fulfillment by the "R & D" side should be a workable arrangement, an improved coordination all along the line with Fleet personnel is required. There is also a need for better education of the Fleet on what each requirement is intended to do and how its results are to be employed by the Fleet. This sort of liaison should reveal weak points early and prevent getting off the track to the objective. This, then, could be stated as problem number six, although it is recognized as not being a case of fulfillment by survey or data handling effort. Our need in the Fleet is for materials easily understood, clearly applicable, and education of the user to make best use of them.

OCEANOGRAPHIC REQUIREMENTS OF THE SERVICE FORCE, U.S. ATLANTIC FLEET

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ABSTRACT

Object: Presents the mission, tasks, and services of the Service Force requiring oceanographic support.

Scope: Discusses environmental requirements of underway logistics, including replenishment alongside, vertical replenishment, and towing. The impact of new techniques and ships is discussed. Ocean Engineering tasks and capabilities are reviewed.

Specific Questions and Requests:

a. Critical review of environmental support for surface and subsurface operations.

b. Review and updating of capabilities and limitations of deep submergence vehicles, deep diving systems, underwater search systems and techniques, object recovery, precise navigational systems.

BODY

MISSION

The mission of the Service Force includes underway logistic support, salvage, and varied ocean engineering tasks.

LOGISTIC SUPPORT

Underway logistic support is continually evolving. Probe refueling, STREAM (Standard Tension REplenishment Alongside Method), VERTREP (VERTical REPlenishment), and "conventional" alongside replenishment is accomplished by older single product ships--AO, AF, AE--and multi-commodity ships--AO(jumboized), AFS, AOE, AOR. Limitations imposed by wind and weather are still present. The newer ships are larger, are affected differently, and have an increased vertical replenishment capability. Environmental forecasts--weather, wind, and sea--are required and the products of the weather service must be responsive to evolving requirements.

The statement of these requirements, the recognition of inadequacies and possible areas for improvement are becoming more difficult with the increasing specialization of personnel.

Logistic support includes towing. The ATF and ATA are small ships and once committed to an extended transit need all the help they can get. Usable information--surface currents, drift predictior ·is sparse and, in the final analysis, largely intuitive and derived f the seamanship of individual commanding officers.

Our requirements for environmental predictions are unabated; my plea is that while today's services are good we must have continued critical review and responsiveness to the seaman's needs.

SALVAGE

Salvage is a complex, demanding, and intensely pragmatic task. Underwater search often precedes the salvage effort--the U.S. Navy Supervisor of Salvage has specialized resources but the service force is usually unable to conduct a search. Once downed aircraft or underwater objects have been located we can recover in diveable waters; otherwise, we must look to outside assistance. We need help for underwater location, search techniques, precise navigational systems, and object recovery. The capabilities and limitations of state-of-the-art deep submergence vehicles are of great interest to us. The deep dive systems coming into service will increase our requirements for specialized environmental knowledge and prediction--bottom currents, temperature visibility, improved diver or vehicle mobility, underwater monitoring and search equipment, underwater navigation and control of deep submergence vehicles.

OCEAN ENGINEERING

I have chosen this phrase to describe some of the esoteric capabilities and requirements of the Service Force. Last winter's recovery of the SNAP 7-E Acoustic Beacon off Bermuda for the U.S. Navy Underwater Sound Laboratory was a routine task for the USS AEOLUS (ARC-3). Cableships have unique capabilities for underwater recovery--including lifts of up to 50 tons and grapnelling to any depth. U.S. Navy cableships are dedicated to sensitive projects; the Underwater Sound Laboratory has been requesting services--to no avail--off Bermuda and the Bahamas for several years. Highly specialized, detailed bathymetry under the closest control is required. Present techniques for fine grain surveys are time consuming and demand the dedication of highly trained, sophisticated forces.

PRECISE POSITIONING CONTROL

The LORAC Support Teams were organized to provide positioning control for coastal cableship operations. These teams are now represented by the U.S. Navy Navigation Aids Support Team, assigned to Commander Service Squadron EIGHT in Norfolk. The NAVAIDSUPTEAM is tasked worldwide to support specialized projects, NAVOCEANO and the U.S. Navy Underwater Sound Laboratory.

The NAVAIDSUPTEAM is equipped with DECCA LAMBDA, DECCA HI-FIX and RAYDIST systems. HI-FIX and RAYDIST equipments can provide positioning control within about two hundred miles of selected shore sites to accuracies of better than six meters. This capability has not been employed by Amphibious Forces and only to a limited degree during mine warfare operations. Neither additional equipments nor personnel can be justified unless there is an actual need for services--their usefulness is demonstrated by commercial use of these systems for offshore oil exploration.

OPNAVINST 544C.71 describes the NAVAIDSUPTEAM and the mode of requesting services.

The problems encountered by the NAVAIDSUPTEAM are beyond the scope of oceanography but are met by NAVOCEANO--they include radio wave propagation, geodesy, frequency interference, site selection, and so forth. Precise positioning services are available and can be obtained from U.S. Navy assets and from commercial sources.

AMPHIBIOUS FORCE OCEANOGRAPHIC PROBLEMS

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ABSTRACT

Oceanographic problems which relate to the Amphibious Force pertain to sea state and surf conditions in the Amphibious Objective Area (AOA). There are five topics which relate to these conditions wherein discussion and research is desired:

(1) Establishment of an oceanographic data bank and computer program which provides effective surf predictions for contingency planning and operations.

(2) Continued research to develop a surf forecasting method that is theoretically sound and will provide an accurate forecast when programmed with good initial data.

(3) Reevaluate the objective method for determining surf effects on landing craft.

(4) Develop new measuring techniques and instruments for gathering required surf data.

(5) Develop a wave suppression method that would be applicable for use by the Amphibious Force.

DISCUSSION

Oceanographic elements with which the Amphibious Force is primarily concerned relate to sea state and surf conditions. Before the Amphibious Task Force Commander (CATF) can give the order "Land the Landing Force", he must ascertain that sea conditions are such that ships can dependably launch a variety of amphibious assault craft and that the craft can safely traverse the hazardous surf zone. Thus, in both planning and executing a water borne assault, the primary determinants for the type and timing of the operation are sea and surf conditions within the Amphibious Objective Area (AOA). Of these two, surf conditions are of greater concern to the CATF.

In order to point out areas wherein exists a need for the oceanographic community's assistance, the amphibious operation is divided into the planning and execution phases.

During the planning phase, the information required for computing effective surf heights establishes the first area in which assistance is requested. Prior to the deployment of Underwater Demolition Teams (UDT) or reconnaissance personnel, which provide the CATF with first-hand surf data, the commander must rely upon the forecaster's product. In preparing his forecast the meteorologist must study a variety of information available to him, such as National Intelligence Surveys (NIS), beach studies, nautical charts of the area, and Fleet Weather Central (FLEWEACEN) weather and sea forecasts. From these sources, if they are available and up to date, the forecaster obtains insight into the climatology and beach characteristics in the AOA. Utilizing the SVERDRUP-MONK method, with its simplicity and ease of employment, a sea and swell forecast is prepared. This is followed by a surf forecast for the assault beach utilizing the techniques set forth in the Surf Forecasting Manual (1). Once this is accomplished, the surf parameters are then modified to obtain the effective surf height forecast.

This procedure is tedious, time consuming, and only as accurate as the initial data from studies. To overcome some of the inaccuracies and provide the best forecast possible, a data bank could be established at FLEWEACEN which would provide updated predictions of surf conditions for contingency plans. Close coordination between the Oceanographic and Intelligence Communities would be required, but this would enhance the availability of oceanographic information necessary for current operations.

"Superior numbers in parentheses refer to similarly numbered references at the end of this paper."

Once the oceanographic/hydrographic information is obtained, a computer program should be developed to incorporate the various parameters necessary to compute effective surf heights for the desired AOA and assault beaches. Information in the program must include beach gradient and other hydrographic data; local climatology, such as sea/swell and weather conditions; shoaling and refraction data at prescribed increments of wave direction and period; and modifications required to obtain effective surf directly. The computerized data could be reduced to a series of nomograms for insertion into contingency operation orders for use by the forecaster. The nomograms would permit a nontechnical operational prediction method and allow for rapid update.

As previously mentioned, surf forecasts are required during the planning phase and also prior to the arrival of the Amphibious Task Force in the AOA. It is understood within the oceanographic community that a reliable surf forecasting technique is not yet available. Therefore, it is desired that continued research be programmed in order to obtain an accurate surf forecasting method. It is obvious that such a technique would greatly enhance the Amphibious Force Commander's knowledge of conditions he might expect to encounter on D-Day.

One of the basic areas requiring additional research is that of effective surf heights, important to both operational phases. The Amphibious Force has established the effective surf height calculations from empirical results from experience gained in conducting amphibious operations in the 1940s.(2). This effective surf is an objective method defined as a modification of the significant breaker height and expresses the total surf conditions likely to be encountered. It is expressed in feet and when calculated from a known or forecasted surf condition, provides a guide for judging the feasibility for each type of landing craft to safely navigate through the surf zone (Table 1).

In actual practice, effective surf is derived by applying a weighting factor to appropriate surf parameters in accordance with given formulae or applicable tables. The sum of these weighting factors is then added algebracially to the significant surf height to arrive at the effective surf height. The surf parameters which undergo modification to determine the effective surf are breaker period, type and angle; littoral current; wind direction and velocity; secondary wave heights; and significant breaker heights (Table 2).

The original work and accumulation of data in formulating the objective method was performed near the end of World War II (3). It is pointed out that the method may not correctly reflect conditions for today's landing craft (4), and that the original data was biased toward long period waves (1). Therefore, it is desired that the objective method be evaluated for landing craft in use today, as well as updated for future craft, and that any necessary improvements be made available to Amphibious Type Fleet Commanders.

In the operational phase, the surf forecast is modified for existing conditions just prior to and during the actual landing. This is a critical period and demands reliable data of the current situation. Present measuring techniques and available instrumentation for gathering surf data is considered substandard. New techniques and accurate instruments are needed to support the observers, who are often inexperienced, and improve the methods presently used. This point is discussed in a paper which will be presented during the Amphibious Warfare session.

The final area where research is desired is in wave suppression methods. Once the Amphibious Landing Force is in the objective area and final sea and surf conditions exist that prevent the landing from taking place, it would be ideal if a method existed whereby high sea and surf could be suppressed to permit safe landings. It is recognized that research in this field is being conducted; but a major breakthrough would greatly enhance the capability for water borne landings during adverse conditions. Whether the method be a rechanneling of wave energy, a chemical or oil spray on the waves, or interference created by mechanically produced waves, the technique developed must be capable of being used by the landing force over a short time period. Also the system developed must enable the Amphibious Force to retain an element of surprise and not consist of such an elaborate system that its use would reveal to the enemy the impending landing.

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TABLE 1

Maximum Surf Heights for Training Operations

CRAFT/VEHICLE	MAXIMUM BREAKER	MAXIMUM EFFECTIVE SURF (FT)
LCM-6	6	7
LCM-8	7	8
LCU	8	9
LCVP	5	6
LVTP 5	10	11
LVT(R)	6	7
DUKW	5	6
CAUSEWAY (3'X15')	7	8
Self Propelled Barge (Pontoon)	6	7
Warping Tug (Pontoon)	7	8

TABLE 2

EFFECTIVE SURF CALCULATION

SIGNIFICANT BREAKER HEIGHT - - - - - - - - - - - - - - - - - - - ____________

BREAKER PERIOD - ____________

Adjustment Value

Significant Breaker Height	1-3.9	+.5	0	0	0	-1
	4-5.9	+1	+.5	0	0	-1
	6-7.9	+1	+1	+.5	0	-1
	8-10	+1	+1	+1	0	-1
	Breaker Period	3-5	6-8	9-11	12-16	over 16

BREAKER TYPE - ____________

80-100% Spilling -1
21-69 % Plunging 0
70-100% Plunging +1

BREAKER ANGLE - ____________

4°R to 4°L 0
5° to 9° angle +.5
over 9° angle +1

LONGSHORE CURRENT - ____________

0 to 0.9 knots 0
1.0 to 2.4 knots +.5
2.5 to 3.9 knots +1
over 3.9 knots 1/2 speed

WIND DIRECTION/SPEED - ____________

Wind Speed	0-10	0	0	+.5
	11-20	0	+.5	+1
	21-25	+.5	+1	+1.5
	26-30	+1	+1.5	+2
	31-35	+1.5	+2	+3
	36-40	+2	+3	+4
		60°-90°	30°-60°	00°-30°

Wind Direction Relative to Beach

EFFECTIVE SURF (TOTAL) - - - - - - - - - - - - - - - - - - - ____________(FT)

Knowledge for Working in the Sea

FLEET SALVAGE

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ABSTRACT

The escalation of hostilities in Southeast Asia pointed up the inability of the Navy's in-being towing and salvage to meet the large increase in salving and towing operations. Additionally, equipments and methods being used had not improved since World War II. To correct the situation, ships were leased or activated, obsolete equipments were replaced and additional personnel trained. The salvage of the USS FRANK KNOX (DDR 742) was the first use by the Navy of foam for dewatering flooded spaces. Numerous other salvage operations, such as USS CLARKE COUNTY (LST 601), were conducted using more conventional methods. In addition to these existing salvage techniques, the Navy has a requirement for the capability to raise large objects up to the size of submarines from deep depths. The Large Object Salvage System (LOSS) concept is planned to meet this problem. Additionally steps must be taken to provide greater capabilities to the working diver.

The period 1965-1969, with the escalation of the conflict in Southeast Asia necessitated a concurrent enlargement of the fleet's support forces. As Commander Service Squadron Three the Seventh Fleet's logistic support force from September 1968 to October 1969, I was intimately involved in this expansion.

Of particular importance was the Pacific Fleet salvage force. Through 1964 and into early 1965 this force consisted of

- 18 fleet ocean tugs (ATF)
- 8 salvage ships (ARS)
- 8 auxiliary tugs (ATA)
- 1 salvage ship (ARS) (civilian manned)
- numerous harbor tugs scattered throughout the various Naval Districts and Bases.

As in-country forces were strengthened throughout 1965 with a resultant tremendous increase in ship movements from both coasts of the United States to South Vietnam, there was an almost immediate quantum jump in the calls for salvage and towing services resulting from:

- Groundings
- Collisions
- Mine Explosions
- Underwater Swimmer Attacks
- Breakdowns
- Rocket attacks
- Storm damage

Many factors contributed to the groundings.

- Minimal or non-existent navigation aids
- Unpredictable currents
- Shifting channels
- Retrieval crews manning activated merchant ships

In order to man the numerous merchant ships that were activated during the period, it is interesting to note that the Maritime Union hiring halls were swept clean. Men who had not been to sea for as many as twenty years were being called upon to serve as first or second mates responsible for ocean transit. Their long years away from the sea and consequent rustiness in the arts of seamanship and navigation were probable contributing factors to the numerous groundings that occurred.

In addition, a decision made in the late 1940's came home to haunt us. This was the decision to remove radio direction finders from Navy ships. As a result, even though a broken down merchantman could and would transmit, the Navy's salvage and towing forces were unable to receive the signal and home in on the aimlessly drifting ship. On numerous occasions it was necessary to launch an aircraft, have it home in on the signal and then vector the salvage and towing forces to the distressed vessel.

The salvage and towing resources, limited as they were, were stretched to their utmost. Operation priorities had to be set and precious time was being lost in getting war cargo and other materials to the end users.

As a result of these increasing demands for services, the Chief of Naval Operations and the Commander Naval Ship Systems Command in 1965 deemed it prudent to take the following immediate steps

- Lease two British Lift Craft based at Singapore
- Lease two British Heavy Lift Craft based in Scotland
- Create Harbor Clearance Unit One

These units were all prepositioned in the Western Pacific to be immediately available for emergent in-country salvage tasks.

The decision in 1966 to create the Mobile Riverine Force for duty in the Mekong Delta created an additional requirement for men, material and craft to conduct riverine and harbor salvage, clearance and towing.

An emergency program was begun immediately to:

- Convert LCU's into light lift craft
- Procure two German heavy lift craft
- Activate and convert a net laying ship into a diving and salvage platform.
- Convert LCM's into diving and salvage workboats.

The introduction, by the Viet Cong of mines into the main ship channel resulted in immediate casualties to shipping and necessitated the use of mine-sweeping boats.

Accelerated enemy action in all areas from the Delta to the bomb line caused additional sinkings or heavy damage from mines, swimmer or rocket attacks. The magnitude of the work taxed the salvage force to its limit.

The numerous salvage operations in 1965 and 1966 reemphasized the fact, brought out during the salvage of the USNS CARD at Saigon in 1964, that the gasoline driven World War II salvage equipments were:

- Unreliable for extended use
- Hazardous to operate
- Not easily maintainable
- Not fully supported in the supply system

Made aware of the seriousness of the problem, steps were taken by Naval Ship Systems Command personnel, to implement a replacement program utilizing diesel driven equipment.

New pumps, generators, compressors, welding machines and salvage winches were provided. This new diesel driven equipment significantly enhanced salvage force readiness posture and contributed markedly to the successful salvage of numerous ships, craft and aircraft.

Although the salvage ships (ARS) and fleet ocean tugs (ATF) bore the brunt of the many salvage and tow assignments, we were most fortunate in having two auxiliary tugs (ATA) assigned at all times. These two smaller tugs were invaluable for towing barges and craft to and from Vietnam. They were also able to provide coastal tow services, thus enabling freeing larger ARS and ATF for deep water tow and salvage.

As units of Harbor Clearance Unit One began to arrive in country, they assumed responsibility for river and harbor clearance and salvage. The salvage ships and fleet ocean tugs could now concentrate their efforts on offshore problems.

By far the most interesting and challenging of the offshore operations of recent years took place during this period. This was the salvage of the USS FRANK KNOX (DDR-742).

On 18 July 1965, FRANK KNOX, enroute from Vietnam to Taiwan, while steaming at 16 knots ran hard aground on Pratas Reef, which is about 180 miles southeast of Hong Kong. (Illustration #1)

Initial surveys, made by a team of Chinese Navy UDT divers, stationed on nearby Pratas Island, the morning of the 18th, disclosed that the ship was aground from forward of the forward five inch gun mount to an area beneath the after fire room. In addition, the sonar dome was sheared off.

Within hours USS GRAPPLE (ARS 7), USS MUNSEE (ATF 107) and USS COCOPA (ATF 100) which were all within one day's steaming of the area, were ordered to the scene.

Initial efforts in salving involved the use of tried and true conventional methods such as pulling with beach gear and the off-loading of weights represented by ammunition, fuel and water. An initial pull made on 20 July succeeded in moving FRANK KNOX 12 feet toward open water. The next pull was planned for the following day.

That afternoon, however, the weather worsened as Typhoon Gilda passed south of the area. During the passing of the storm, it appeared very likely both FRANK KNOX and her crew would be lost. As a precaution Commander Seventh Fleet ordered USS MIDWAY (CVA 41) and the amphibious task group with USS IWO JIMA (LPH 2) to proceed to the scene to effect helicopter evacuation. Before the operation ended, the ships listed below were assigned to the salvage.

ADDITIONAL FORCES

1. MIDWAY (CVA-41)	6. GREENLET (ASR-10)
2. IWO JIMA (LPH-2)	7. PRAIRIE (AD-15)
3. CONSERVER (ARS-39)	8. POINT DEFIANC . (LSD-31)
4. SIOUX (ATF-75)	9. TALLADEGA (APA-208)
5. MARS (AFS-1)	

It soon became evident FRANK KNOX would in fact survive and evacuation was limited to 155 non-essential personnel.

After the typhoon cleared the area, it was apparent that a simple refloating problem was now a major salvage operation. As a result of the storm, FRANK KNOX had moved laterally on the reef about 75 feet and had entrenched herself in the coral.

This second phase of the operation required the formulation of a new plan of attack. The basic plan now was to rig additional pulling force and to dewater the forward engineering spaces.

Three more towing and salvage ships were ordered to the area to assist in rigging additional beach gear to provide a greater pulling force. At the same time boiler repair personnel from the USS PRAIRIE (AD 15) effected repairs to #3 boiler in order that power might be maintained. Feed water was lifted to KNOX by helicopter in 150 gallon tanks.

Pumping of the forward engineering spaces was largely unsuccessful although extensive patching was done on the hull. On 25 July another pull was attempted and although the ship shuddered, no movement was detected.

On 26 July, another pull which included backing on FRANK KNOX port engine, was attempted. Part of the beach gear carried away, and after moving about 30 feet, KNOX swung about 15 degrees towards a broaching position. Typhoon Harriet now passed near the area, but the salvage force held on to KNOX and rode out the storm.

The third phase began with the replacement of beach gear lost during the storm and the rigging of additional gear to pull the stern to starboard and thus follow the easiest path to deep water.

Pumping of the forward engineering spaces was proceeding unsatisfactorily so it was decided to dewater the spaces with air. Numerous leaks foiled this effort. On 30 July, another unsuccessful pull was attempted.

At this point it was decided to try using cast-in-place foam if the next pull was unsuccessful. 40 tons, which would provide 800 tons of buoyancy was ordered.

On 31 July using FRANK KNOX's port engine and five towing and salvage vessels, an attempt was made to wrench the stranded vessel loose. She moved about six feet astern and her heading was improved 23 degrees. On 2 August another attempt was made to float KNOX, however this also failed.

Then began phase four of the operation which involved rerigging of all beach gear, the selective use of foam and coral blasting. At this time, all compartments forward of frame 110 were open to the sea. Number four boiler was operational, and the after turbo generator was providing power aft. The forward emergency diesel generator was providing power forward. Feed water was carried to the ship by helicopter, LCU or LCM.

All beach gear was rerigged to FRANK KNOX, as experience had shown, gear rigged to the salvage ships had tended to drag due to pitching of ships in rough weather. Six sets were rigged.

Meantime foaming had begun. Forward tanks were done first as a trial. Foaming was done by drilling a hole in the deck and then inserting the foam gun barrel. The amount of dewatering actually taking place was estimated by the amount of foam expended.

Foaming continued until 20 August at which time the forward engineering spaces and forward tanks and voids were foamed as shown in illustration #2. On 12 and 13 August unsuccessful pulls had been made. As an additional means of assisting retraction USS MARS (AFS 1) made high speed runs offshore in order to make waves in the otherwise calm sea.

On 22 August, another pull was made, with a resultant 10 degree improvement in ships head and movement aft of about eight feet. Also a great portion of the hull was now free of the coral.

On 23 August, another attempt was made and again some astern movement was detected. USS COGSWELL (DD 651) made high speed runs across the stern of KNOX to create swells.

The morning of 24 August another attempt was made. By this time FRANK KNOX's boiler was useless as several tubes had ruptured and her engineering plant was useless. COGSWELL had four boilers on the line and was standing by. Heaving started at 0230 and COGSWELL started full power runs at 0330. At 0420 movement was detected each time COGSWELL's waves reached KNOX. At 0520 as COGSWELL's waves reached the shore, the stranded ship lunged about five feet aft. The beach gear quickly took up the slack and at 0530 after five weeks, FRANK KNOX came free.

She was towed several miles to sea, where she was picked up and towed by USS CONSERVER (ARS 39), stern first to Kaohshiung for emergency repairs, and finally to return to an active status about a year later.

This first use of foam by the Navy for dewatering a ship showed the following advantages:

- Materials for foam are air transportable
- Foam can be installed from within or without a space.
- A means now exists to dewater a compartment which cannot otherwise be made tight for pumping or blowing.

However, although the use of foam did in fact prove to have several advantages, disadvantages did in fact exist:

- Expensive and requires use of specially trained personnel.
- Toxic
- Foam must be contained, or it may well wash out.
- Flammable
- 100% dewatering is not guaranteed by use of foam.
- Foam removal is difficult and expensive.

Another interesting, but extremely difficult salvage operation was the retracting of the USS CLARKE COUNTY (LST 601). On 16 November 1967, while attempting to beach at DUC PHO, CLARKE COUNTY fouled her stern anchor wire in her starboard screw and broached on a sandbar (Illustration #3).

As well as being broached, her bow doors were open and she was taking on water. In addition, she was pounding on two sunken LCM-8s.

Initial inspections revealed a major salvage effort was necessary, if CLARKE COUNTY was to be saved. Pounding on the LCM's increased early damage. Also, a northerly on-shore current was moving the ship steadily northward, causing the whole portside to be progressively battered and holed in many places. The sustained damage extended inboard to the centerline compartments. Eventually all portside compartments and tanks, with the exception of the after magazines, were flooded. The bow doors were swinging free, and there was four feet of water in the tank deck. Other damage included uncontrolled flooding in:

- Compartment C-410-W
- AC Generator Room
- Boiler Room
- Beaching Tanks
- Forward Pump Room

Although USS NAVARRO (APA 215) furnished damage control personnel and equipment in an effort to stop the spread of flooding by the afternoon of the 17th:

- Main Engine Room flooded
- Auxiliary Engine Room flooded
- All electrical power was lost
- Ship became unseaworthy

Major repairs were now necessary before floating could be attempted.

The first salvage force ship USS UTE (ATF 76) arrived on the scene shortly after noon on the 17th. UTE's salvage party and salvage equipment were transferred to CLARKE COUNTY by means of an Army BARC. Internal damage control efforts were intensified. However, the heavy surf precluded using divers to make underwater repairs.

USS BOLSTER (ARS38) arrived on the scene that evening. The BOLSTER crew had been augmented by personnel from Harbor Clearance Team 5. The BOLSTER salvage party boarded CLARKE COUNTY with their equipment. Sufficient personnel were now available to set up twelve hour shifts. Each shift was composed of:

Functional Teams

- Pumping
- Repair
- Investigation
- Electrical Repair

This remained the salvage party organization throughout the remainder of the operation.

On 18 November dewatering efforts commenced. Damage control measures continued and were aimed toward restoration of minimum seaworthiness.

On 19 November it was decided CLARKE COUNTY's bow should be pulled around to seaward so as to prevent sand buildup amidship, as this buildup could well break the ship's back.

Meanwhile, helicopters continued to shuttle men and materials to CLARKE COUNTY.

On the 20th UTE commenced heaving on her beach gear and gradually pulled the ship around into the sea. CLARKE COUNTY pivoted on her stern, which was held fast with lines run to Army tanks on the beach. At night these tanks would take up defensive positions around the area.

On 21 November USS MARS (AFS-1) arrived with CTF 73 embarked. CTF 73 now assumed the duties of on-scene commander.

The arrival of MARS meant continuous helicopter lift support was now available for the lift of personnel, equipment and food to CLARKE COUNTY. Without MARS helicopters the remainder of the operation would have been even more difficult than it turned out.

The surf now calmed sufficiently to permit divers to enter the water for the first time. Patching was determined to be impossible.

Again, as in the FRANK KNOX salvage, the use of foam was considered for dewatering, but it was not used since it was felt its use would increase the ultimate cost of repairing the ship. It was decided the old reliable standby compressed air, could do the job. Air compressors were heloed to the ship.

The period 22-29 November was spent in dewatering compartments and tanks, rigging temporary lighting, laying additional sets of beach gear, securing the bow doors, removing the maximum amount of weight, installing towing points and rigging wash-out nozzles.

On 26 November, one of MARS helicopters went into the water and subsequently sank, in spite of vigorous efforts to save it. Fortunately all personnel were saved.

On 30 November all was in readiness for a maximum pull. BOLSTER, UTE and ABNAKI were designated pull ships. Again, the Army was called upon and provided tanks to hold the steadying lines leading from the stern.

As the pull ships took a steady strain, forward motion seaward was noted. The tanks moved slowly down the beach, allowing the steadying lines to slacken. CLARKE COUNTY continued her forward motion and as the tanks reached the waters edge all steadying lines were cast off. She continued moving seaward, and early on the morning of 1 December she slid easily into the sea.

BOLSTER took CLARKE COUNTY into tow for Danang, with all excess personnel being removed by helicopter. Although she had a severe port list, and was down by the stern, CLARKE COUNTY was secure for sea. She arrived safely at Danang on 2 December.

I have discussed the successful salvage of two stranded ships. Let's look at our capability to raise sunken ships.

Until recently, the depths at which major salvage tasks could be undertaken, were for the most part limited by the maximum working depth for divers, that is, 380 feet.

Recently, we have been successful in locating and raising small objects from deep depths. In 1969, ALVIN, a deep research vehicle, was located and recovered from over 5000 feet of water. Also in 1969, a sophisticated device, was relocated and recovered from a 16000 foot depth.

In March of this year, utilizing CURV III, we located and recovered the Solar Eclipse instrumentation package from almost 6000 feet.

However, in conjunction with man's ability to work in the sea. there exists the requirement to lift large objects from extended depths, as the salvage of sunken vessels can have military, economic or political significance.

If the hull is essentially intact recovery becomes economically advantageous, due to the dollar value of the salvaged object. Even if the hull is not intact, recovery of appropriate parts will permit investigation into the cause or causes for the loss and could lead to the formulation of design improvements and/or changes in operational procedures. If the craft is nuclear powered or carries nuclear devices, there may well be political considerations that can be satisfied only by the sterilization or removal of the nuclear components.

The Large Object Salvage System (LOSS) which is presently still a concept, will provide the capability for recovering submarines from depths to 1000 feet. In addition to raising submarines, the system must be adaptable for recovery of other objects such as submersible vehicles, surface craft, aircraft and certain weapons such as torpedoes and nuclear devices. This system must have sufficient flexibility to insure that those responsible for a particular operation can select a system configuration compatible with the task at hand.

Unfortunately, submarine salvage techniques have experienced little improvement since the recovery of the S-51 from 132 feet in 1925. The depths at which major salvage tasks can be undertaken are for the most part limited by the maximum working depth for divers, that is, 380 feet. In some isolated cases, such as ALVIN, submersibles have been used in salvage operations at greater depths.

Present heavy lifts continue to be made using salvage pontoons controlled with air pumped from the surface, or by lift craft which use the rising tide to provide the required lifting force.

The lift craft are able to lift up to 600 tons utilizing their stern gantry. By using over the side, ballast and/or tidal lift they may lift up to 2400 tons. If two crafts are used, as much as 4800 tons may be raised. However, the necessity for passing cables from the lift craft to the salvage object makes the success of the salvage operation dependent upon weather conditions, sea state and tidal range.

Further, there are a number of operational problems associated with the use of our 80 ton pontoons. Existing pontoons are lowered and attached to the salvage hull via cables which must pass under the hull. This technique requires that cable troughs be tunnelled under the hull; a time-consuming, difficult and often dangerous task that must be done by the diver.

In addition, experience has shown our pontoons to be unstable, both on the surface and after emplacement. Free-surface effect in the partially flooded pontoons is the major cause of surface instability. Stability problems after emplacement stem from the tendency of the pontoons to "duckbill" due to slight buoyancy differences in opposing pontoons.

The Large Object Salvage System (LOSS) concept is planned to minimize existing problems such as:

- Sea state effect upon conduct of the operation
- Surface support required
- Number of lines or cables between the wreck and the surface support ship, as all but the tow line are eliminated

LOSS, as we now see it, will be composed of the components shown in illustration #4. It must be reemphasized, LOSS is still a concept, and when a true system finally emerges, it may not even remotely resemble the one shown. We presently plan to use the LSD for the transport of pontoons, vehicles and ancillary equipment.

In general, the sequence of steps in raising a sunken submarine are:

- Position diver support ship
- Survey with work submersibles/divers
- Send down pontoons
- Attach lift arms
- Break out
- Trim sub
- Raise sub
- At 200 foot depth, cross brace and band
- Continue to surface
- Tow

Illustration #5 gives us a general idea of the general positioning and means employed in preparing to raise the distressed submarine.

The basic concept of LOSS is sound and relatively uncomplicated, however, the individual equipments required are somewhat sophisticated. As can be seen in illustration #6 there are many areas that the Navy and industry must further explore before we can consider LOSS as operational.

Recognizing that LOSS is at this time primarily a concept to be developed over a period of years, there are still major problems facing us today. This is in the area of the working diver.

Today's diving and salvage personnel have marginal tools and equipment for performing work safely and efficiently at 380 feet. However, our ability to dive to 850 feet, with the deep dive system, with further excursions to 1000 feet presents us with problems.

We require tools such as impact wrenches, stud guns, cutting and welding methods that are certified capable of performing at deep depths.

We need certified power sources to run the tools and provide lighting.

Certified gas generation equipment to inflate our collapsible pontoons is required.

Certified and service approved breathing apparatus good to 1000 feet now and 1500 feet in the near term is necessary.

A solution is needed to the diver heating problem that exists below 200 feet.

Resolution of the helium speech phenomena is an urgent problem.

Finally, Navy salvage forces are constantly called upon to locate and recover downed aircraft. The crash site is usually ill-defined, but recovery is required to determine crash cause or for recovery of classified materials.

Our failures in this area far outnumber our successes. We need the capability to locate and recover a downed aircraft even if it should scatter in many pieces over the ocean floor.

The challenge is there. It is now up to the Navy and industry to face up and meet the test.

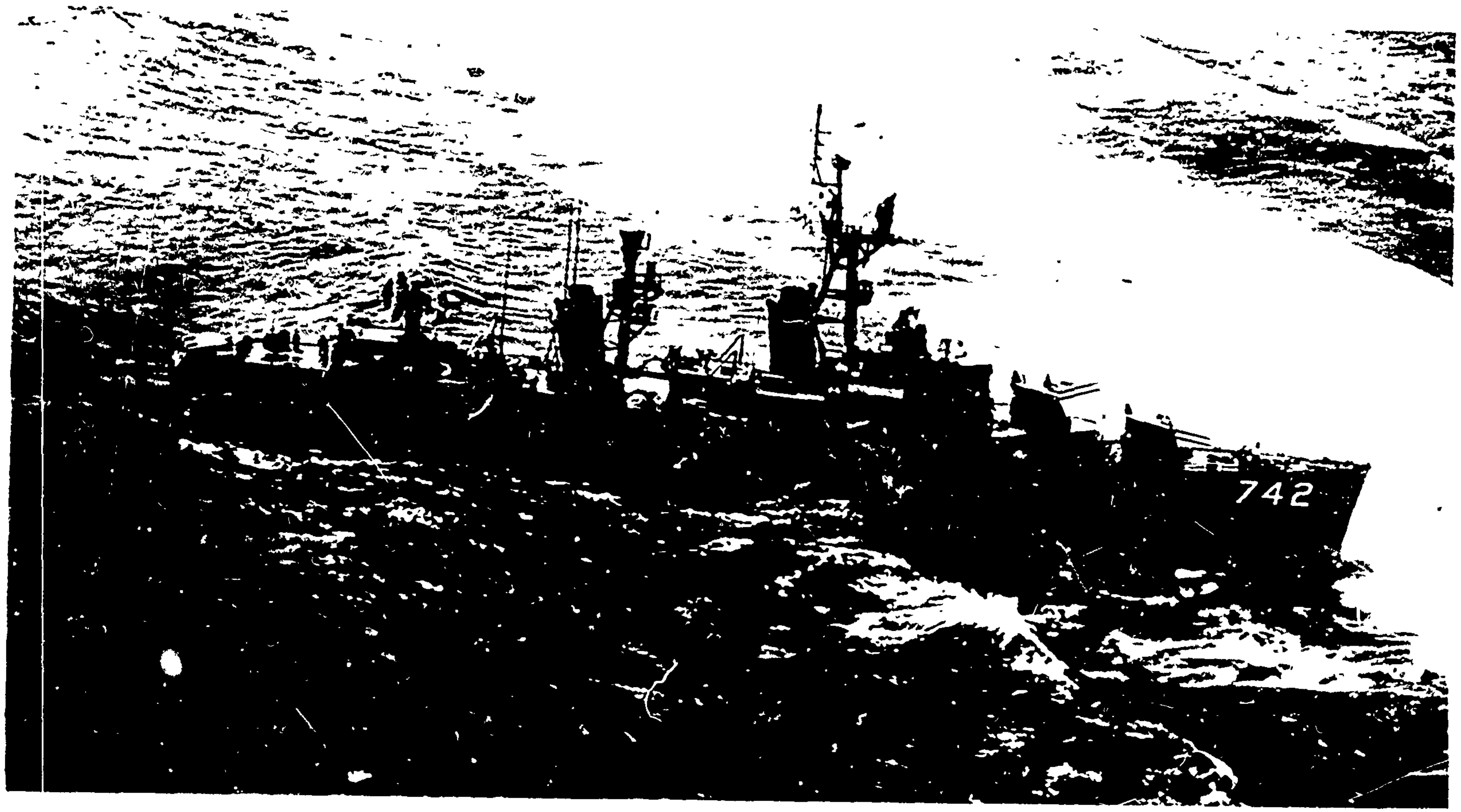

Figure 1
FRANK KNOX Aground on Pratas Reef

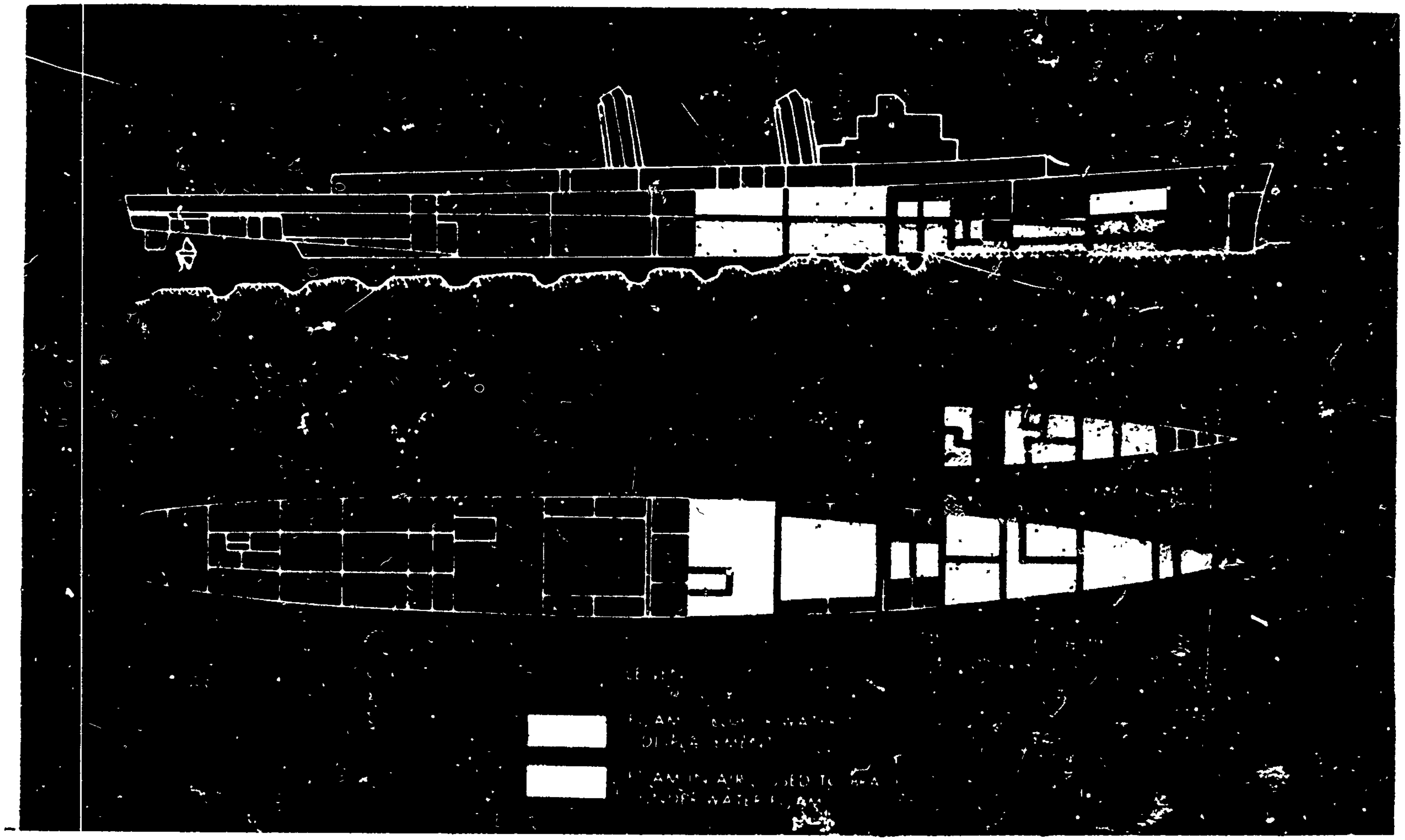

Figure 2 - Use of Foam in FRANK KNOX

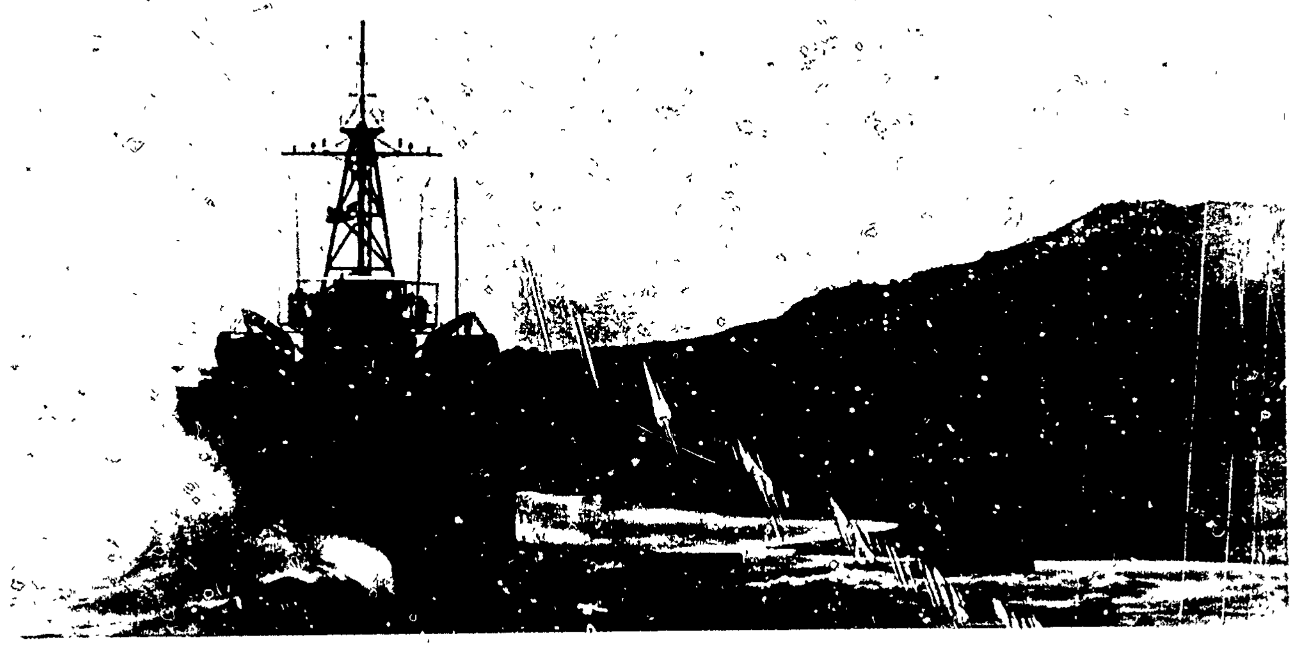

Figure 3
CLARKE COUNTY Aground

- DIVING SUPPORT SHIP WITH AVAILABLE DEEP DIVING SYSTEM
- LSD TO TRANSPORT PONTOONS, VEHICLES, AND ANCILLARY EQUIPMENT
- PONTOONS: 300T, 20 x 40 FEET
  150T, 15 x 30 FEET
- WORK SUBMERSIBLE: DRY, 1-ATMOSPHERE, BATTERY-PROPELLED
- INSTRUMENTATION PACKAGE
- TUGBOAT

Figure 4
Components of Loss

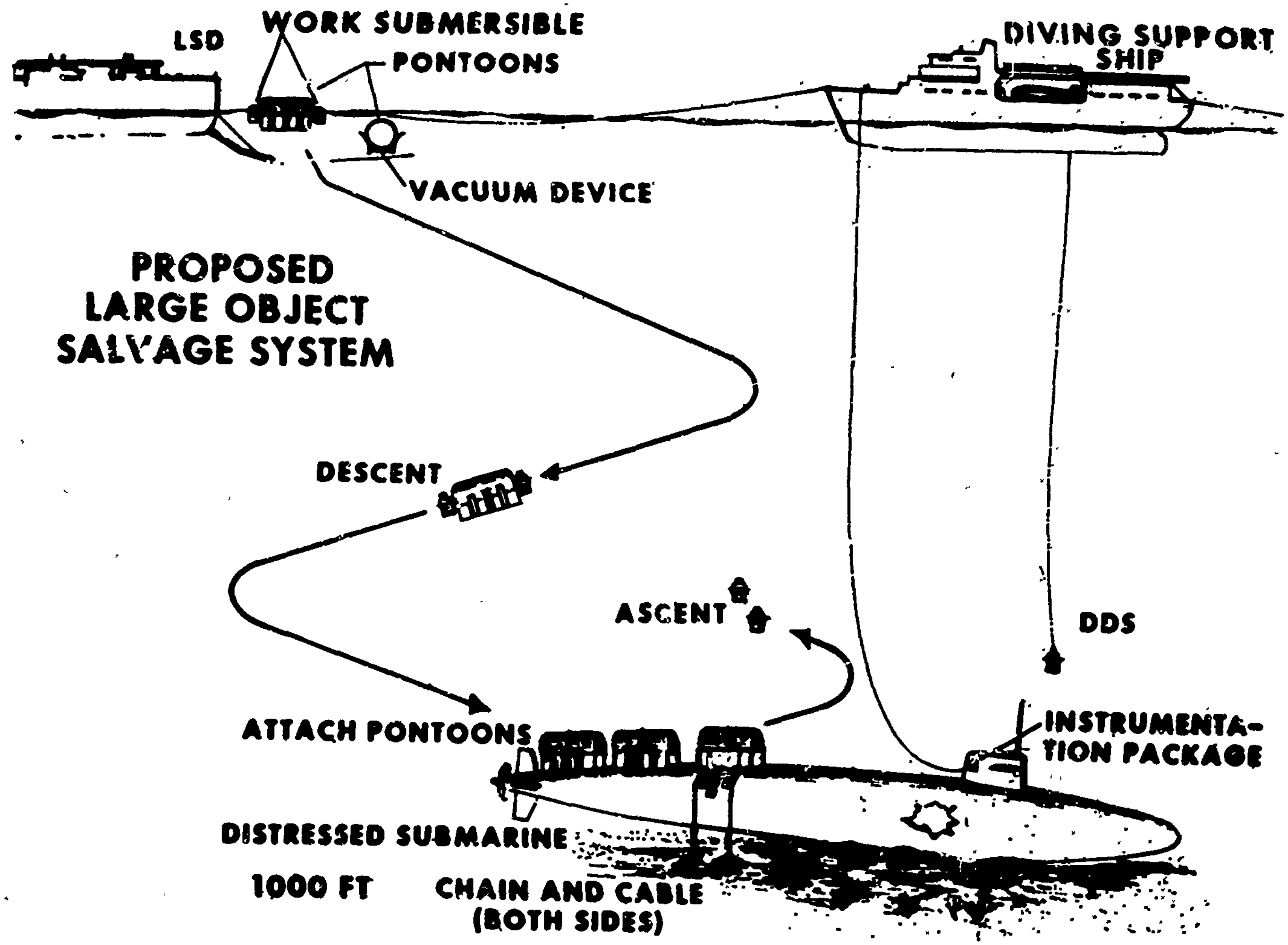

Figure 5 - General Positioning of Loss Forces

PONTOONS	GAS SUPPLY SYSTEM VACUUM SUBSYSTEM ATTACHMENT DEVICES (ARMS) CONNECTORS (ELECTRICAL) CHAIN LOCKERS
WORK SUBMERSIBLE	PROPULSION VACUUM SUBSYSTEM DYNAMIC CONTROL OF PONTOONS PONTOON CONNECTOR MANIPULATOR
CONTROL SYSTEM	SALVAGE CONTROL CONSOLE INSTRUMENTATION PACKAGE COMPUTER PROGRAM
SURVEY SUPPORT EQUIPMENT	RADIATION METER WATER LEVEL INDICATOR SURVEY SONAR

Figure 6
Loss Critical Items

MULTI-PURPOSE DIVING EQUIPMENT FOR THE ENTIRE WATER COLUMN

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ABSTRACT

The Navy diving equipment development program has in the past been centered upon responding to specific missions and partial depth ranges for those missions. As a result of this, we have an excessive quantity of equipment which complicates both diver training and logistic support with an overall detraction from the total diving safety program. Multi-purpose equipment with total water column response from 0-1500 feet has never been achieved, nor for that matter truly attempted. With the advent of new technology in the diving equipment field, increased national interest in putting man at work in the sea and a solidification of Navy management in the ocean engineering area, of which diving is a part, we are now in a dedicated pursuit of modernizing our Diving Navy. This modernization includes the concept of total water column response with one basic unit of diving equipment and limited augmentation of open and closed circuit SCUBA systems.

The Navy endeavor to put man in the sea is not based upon an adventurous program to penetrate record breaking depths with emphasis upon surpassing other foreign powers. Rather, it is a carefully planned program to safely satisfy mission objectives of the Navy. The terms hydrospace and aquanaut are widely used new names with possible glamour appeal but in reality we remain primarily concerned with the sea and the working diver.

The age old adage of, "Beware of the man that over simplifies a problem" is appropriate, yet upon embarking upon a subject such as diving equipment, a few simple base line assumptions must be made and stated in order that we may understand the entire scope of the diving equipment spectrum.

Illustration #1 depicts the fundamental broad categories of diving. It can be seen that as we review each category of diving that concurrently, though not directly, we address diving in water depths ranging from 0-1500 feet associated with specific missions. Review of past Navy diving programs reveals that this fundamental statement, with only minor variations in the maximum depth, was equally valid ten years ago. This maximum depth was predicted not upon limited mission requirements but man's then known physiological and equipment technology limits. The latter limitations have been vastly improved over the last ten years and we now, in addition to these limiting parameters, further categorize the diving equipment requirements into the planning base lines shown in illustration #2.

The mission requirement is self explanatory and need not be amplified at this time.

Item number two is an attempt to preclude wherever possible design/development efforts that are solely responsive to a single small segment of the entire water column.

Item number three encompasses all the good words used by both industry and Navy; such as, quality assurance, cyclic testing, quality control, material adequacy, climatic testing, life support reliability, breathing resistance, human engineering and all the chain reaction phases of systems management. Condensing all of this into everyday engineer/operator conversation it simply means that the equipment is designed to be safely operated to its stated capability by a competently trained Navy diver.

The certification portion is still being formulated, but in essence it is simply the last step in the systematic progression of technical and operational evaluation. It certifies a proven official acceptance of the equipment under the most demanding discipline. This certification sets forth the depth limitation of the equipment and the performance standards that must be maintained.

Item number four, maintenance and integrated logistics support, is a prime consideration. The equipment must be designed to provide routine maintenance and operation without requiring the extended services of the production unit contractor. These simple statements are not profound observations in a new field but have been with us for some extended period of time.

Notwithstanding this, we now have some underwater breathing apparatus that is almost beyond the maintenance capability of the average diver. Complexity has reached such proportions that one piece of equipment requires 45 minutes of pre-dive calibration and then a check list completion time of 30 minutes prior to commencing.

Diving field repair has become extremely difficult due to both the complexity of equipment and the lack of integrated logistic system planning. There is no question that as we progress deeper into the water column there will be an inherent equipment complexity that cannot be reduced by even the most dedicated engineering/operator design team.

Item number five, diver training, is primarily conducted at BUPERS sponsored training activities and the training is concentrated on equipment common to the type of diver to be graduated. We currently have 22 classifications of diver plus diving officers. In diver training, as in any other training, repeated performance with the equipment and a patterned curriculum to acquire total familiarity with the equipment is continually stressed.

We now must exploit to a maximum possible point this mandatory training assumption. We can do this by attempting to provide equipment that covers maximum segments of the water column and further adapts itself to multi-purpose service and the natural accompanying advantage of repeated training in one basic unit.

When you carefully review illustration number #3 you will note that we now have almost twenty major pieces of diving equipment to answer diving requirements of todays Navy. This heavy arsenal of diving equipment is the result of a fragmented mission oriented development at specific depths rather than a concerted homogeneous focus on total mission requirements and total water column response.

To maintain and support this bulging family of equipment is an unacceptable and costly liability. Training becomes so fragmented that diving safety is decreased and the logistic support of literally thousands of individual line items creates a supply logjam.

It must also be noted that this list does not include ancillary divers equipment such as recompression chambers, diver heating systems, diver communication systems and lighting systems which increase our total line item support to staggering proportions. In comparison to total Navy strength we have a relatively small number of Navy divers and certainly a disproportionate amount of equipment to support them. The Supervisor of Diving is attempting to reduce the problems of many years of progressive accumulation in the most timely manner commensurate with present funding support, manpower resources and the medical and engineering technology that is now state of the art.

Illustration number 4 is an artist's concept, based upon our extensive engineering analyses, of a basic unit of diving equipment. Figure A depicts a unit which will serve to replace the current light weight diving equipment and provide a complete shallow water diving system to 130 feet with communications and provision for thermal protection of either a wet suit or dry dress. Our present light weight rig has been involved in numerous diving fatalities and this replacement will eliminate the two major accident causes which are lack of communication with the diver and lack of head protection.

You will see in figure B, that this same basic unit, with the addition of a modularized CO_2 absorbent system, will now provide a mixed gas diving capability to 300 feet and will allow us to retire the conventional deep sea equipment and our 280 pound HEO_2 equipment.

We are planning, in support of OPNAV's diving safety policy, that conventional surface supported diving will be limited to 300 feet and that depths greater than 300 feet will normally require the deployment of an advanced diving system. Working from that assumption you can see in figure C that our versatile basic unit can now be further modularized to include an instrumentation package that will monitor PO_2 and other body functions as required and enable utilization from a personnel capsule. The result is one basic unit, which with modularized additions can respond to the entire depth range from 0-1500 feet.

Illustration number five is a capsule graphic portrayal of the diving equipment spectrum for both the tethered and untethered diver. Certainly no one graph or illustration can convey all information to the viewer but your attention is called to the total water column response and the identification of all mission categories. In this planned approach our goal is to increase diver safety, assist in simplifying diver training, vastly improve logistic support and reduce the numbers of equipments required. At the outset of my presentation I cautioned on the danger of over simplifying and in conclusion it is obvious from recent adverse publicity that complex multi-purpose planes such as the TFX cause controversy and strife. Further, the simple multi-purpose shoe for all military personnel has proven to be an impossible endeavor. However in our select, relatively small community of Navy diving, this universal total response concept utilizing a multi-purpose unit of equipment shows great promise. This single basic unit will be our principal piece of tethered diving equipment. It will be augmented with the minimum numbers of underwater breathing apparatus of the SCUBA and mixed gas SCUBA types.

Figure 1

FUNDAMENTAL DIVING CATEGORIES

1. SEARCH / SALVAGE / RESCUE
2. SHIP HUSBANDRY / UNDERWATER CONSTRUCTION
3. COMBAT SWIMMER
4. EXPLOSIVE ORDNANCE DISPOSAL
5. EXPERIMENTAL

Figure 2

DIVING EQUIPMENT PLANNING BASE LINES

1. MISSION REQUIREMENT
2. TOTAL WATER COLUMN COMPATABILITY
3. SAFETY / RELIABILITY / CERTIFICATION
4. MAINTENANCE AND INTEGRATED LOGISTICS SUPPORT
5. TRAINING REQUIREMENTS

Figure 3

PRESENT NAVY DIVING EQUIPMENT

1. DEEP DIVE SYSTEMS
   - A. MK I DDS
   - B. MK II DDS
   - C. ADS IV DDS
2. CONVENTIONAL DEEP SEA EQUIPMENT
   - A. MK V DEEP SEA AIR
   - B. MKV DEEP SEA HEO 2
   - C. SWINDEL HELMET
3. SHALLOW WATER
   - A. LIGHT WEIGHT (JACK BROWN)
   - B. KIRBY MORGAN BAND MASK
   - C. SINGLE BOTTLE SCUBA
   - D. DOUBLE BOTTLE SCUBA
   - E. NON MAGNETIC SCUBA
   - F. MK VI
   - G. SINGLE HOSE REGULATORS
   - H. DOUBLE HOSE REGULATORS
4. ADVANCED UNDERWATER BREATHING APPARATUS
   - A. MK VIII
   - B. MK IX
   - C. MK X
   - D. MK XI
   - E. SOR 38-02

Figure 4

BASIC DIVING EQUIPMENT

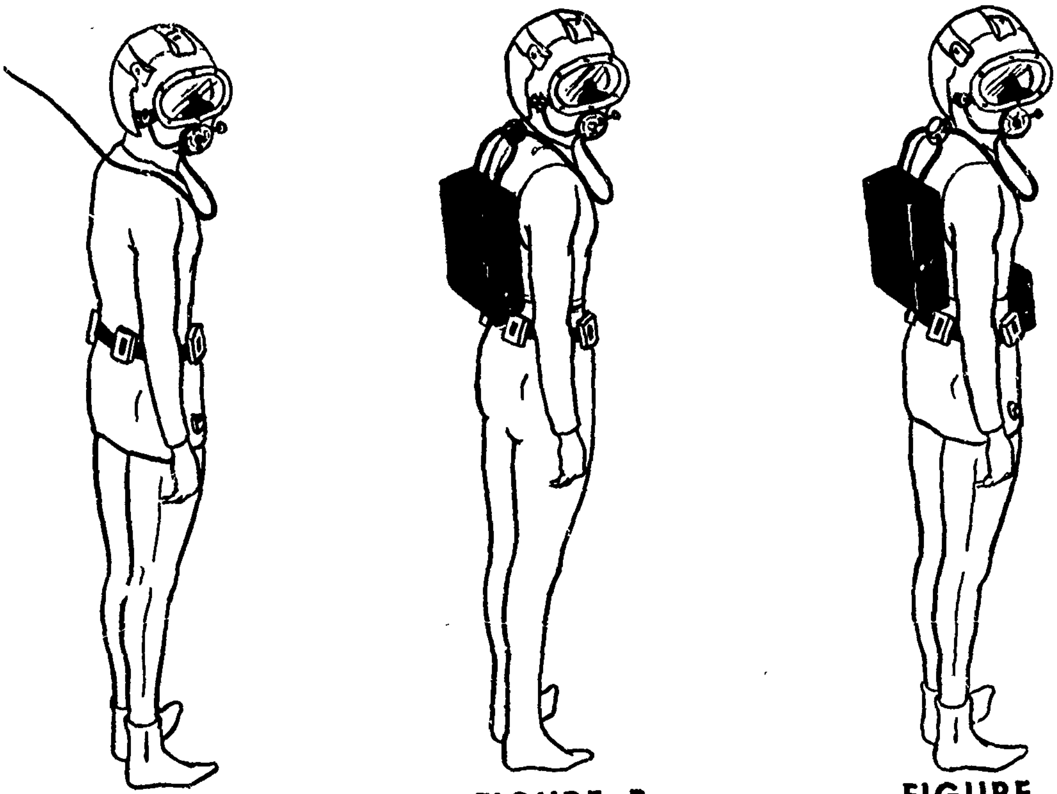
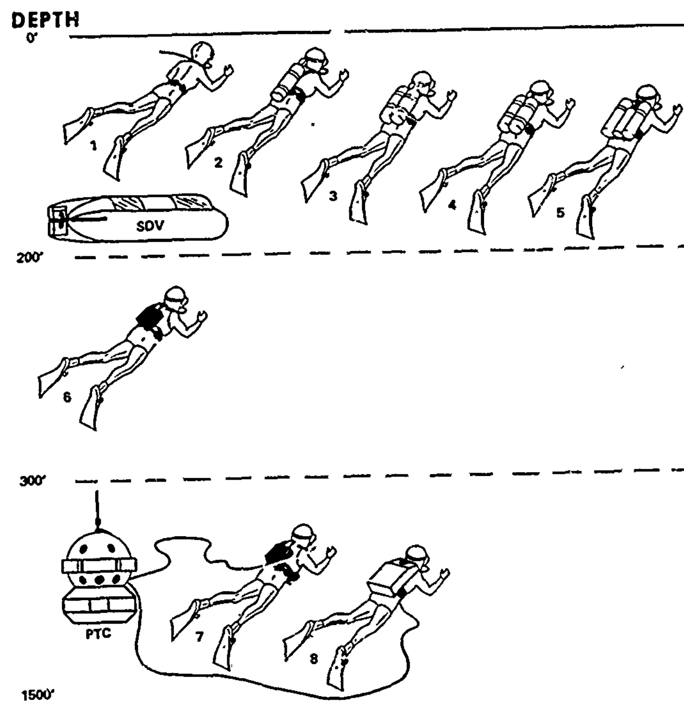


FIGURE A FIGURE B FIGURE C

Figure 5
DIVING EQUIPMENT SPECTRUM



EQUIPMENT	USER
1. TETHERED SURFACE SUPPORT DIVER WITH MULTI-PURPOSE HELMET 2. SINGLE BOTTLE SCUBA 3. TWIN BOTTLE SCUBA 4. NON MAGNETIC SCUBA 5. SOR 38-02/MK VI	1.,2.,3. ALL DIVING ACTIVITIES 4. EOD/UDT/SEAL 5. UDT/SEAL/EOD
6. MULTI-PURPOSE HELMET WITH REBREATHER	6 ASR ATS
7. MULTI-PURPOSE HELMET WITH REBREATHIER & INSTRUMENTATION 8. MK X CLOSED CIRCUIT SCUBA	7.,8. FLEET DEEP DIVE TEAMS

PHYSIOLOGICAL LIMITATIONS OF DEEP SATURATION DIVING

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ABSTRACT

During the decade of the sixties, the technique of saturation diving was developed. To date physiological limitations have not limited the expansion of this technique as a useful tool. Some limitations such as thermal regulation, respiratory airway resistance and communications have proven they will require engineering advances to meet the Navy's objective of a two thousand foot capability by 1980. Projecting the applications of deep saturation diving leads to almost unlimited possibilities for underwater operations and exploration within the confines of the continental shelves and shallow continental slopes.

In July 1964, at a site located on the Plantagenet Bank 26 miles southwest of Bermuda and adjacent to the Argus Island (a Texas Tower structure designed for sonar research) 4 men successfully completed a historic dive to a depth of 193 feet for 11 days. This operation, SeaLab I, was the historic culmination of 7 years of laboratory research to demonstrate the operational feasibility of saturation diving. With its successful completion, the Navy opened the door to vast areas of operational and oceanographic research diving. For the first time the diver was afforded the opportunity to become a part of the ecological makeup of the ocean floor without excessive concern for the limitations of decompression.

As with any new procedure or technique, questions immediately arose as to what limitations man as a physiological animal would place on this new procedure. In the 6 years subsequent to that historic event, relatively few new limitations not previously recognized, have become evident. However, many of the physiological restraints which heretofor had been known but not limiting suddenly gained new importance. It rapidly become evident that as man became a part of this new environment for prolonged periods of time, additional equipment and tighter control of environmental parameters would be required. This new emphasis on physiological limitations demonstrated requirements for further insight into the problems associated with respiratory ventilation while continuously exposed to atmospheres of markedly increased density, further consideration into the problems of inert gas narcosis as associated with helium and, possibly in the future, hydrogen, better control and understanding of the toxicity of trace atmosphere contaminants at increased pressure, the need for additional equipment to provide the diver with proper thermal regulation, aids to improve or new methods of communication in these artificial atmospheres, and a better understanding of the mechanisms and potential hazards of decompression sickness in the immediate and prolonged post-dive periods.

If one considers each of these areas in greater depth and then projects their restraints on saturation diving and the potential applications of saturation diving for military and research application, the future of saturation diving becomes readily apparent.

As long as man continues to be a gas breathing animal for the purpose of oxygen and carbon dioxide exchange across the pulmonary membrane, the density of the breathing media whether it be a helium-oxygen, nitrogen-oxygen, hydrogen-oxygen mixture or any combination thereof, will depend upon the overall density of this media. As the density of any gas increases with increasing depth, we can expect progressive elevation of the work of breathing. This in turn will cause reduction in a diver's capacity for physical exertion. In and of itself this may become the limiting factor. It can be easily seen that a point exists at which the work of breathing alone utilizes the entire energy output of the body. However, prior to reaching this point, there is a progressive reduction in the ratio between work required for breathing and the useful mechanical work that can be performed.

Studies of divers exercising at great depths both with and without breathing apparatus have demonstrated how ventilatory reserve is diminished under diving conditions. Through the use of helium-oxygen breathing mixtures we have a dive system which has been successfully exercised in saturation chamber exposures to 1000 feet, as well as during shorter excursions several hundred feet deeper. Energy requirements alone are not an isolated aspect in considerations of pulmonary ventilation. Further considerations must be given to the exchange of oxygen and carbon dioxide within the lung itself. Ventilation must be sufficient to prevent hypoxia and insure that an adequate amount of oxygen is supplied to the tissues. At the same time this ventilation must insure that carbon dioxide is not retained. It has been repeatedly shown that excessive retention of carbon dioxide compounds other physiological limitations such as inert gas narcosis and decompression requirements as well.

Experiments performed to date on preliminary evaluation indicate that it is reasonable to predict saturation exposures can be safely conducted to depths of at least 1,000 feet with useful work accomplished on short excursion as deep as 1500 feet. Further projections suggest the saturation limits are somewhere between 1500 and 2500 feet. Although, the Navy has not investigated the use hydrogen-oxygen mixes to date as depth requirements in excess of 1500 feet become evident, it would appear almost certain that hydrogen-oxygen or helium-hydrogen-oxygen mixtures may be required. With the advent of hydrogen as the inert portion of a divers breathing media, new problems currently not recognized may also develop.

Further to the consideration of the choice of an inert gas is the consideration of inert gas narcosis. It was for this reason that SeaLab I employed helium-oxygen mixture rather than the cheaper and more readily available nitrogen-oxygen mixture. Although it is possible to dive for short periods of time on air or a nitrogen-oxygen exposure to depths of 193 feet prolonged exposure to this mixture soon leads to incapacitating narcosis. The question then arises what is the helium-narcosis limitation of dives employing helium-oxygen mixes. Various projection techniques have been used to determine where the limiting depth for such a mix will lie. These projections have been based on several different properties of inert gases such as lipid solubility, molecular weight, absorption coefficience, thermo-dynamic activity and the formation of clathrates. To date the most satisfactorily correlation appears to be a relation to lipid solubility. If this fact proves true, it will limit the use of hydrogen because of its increased solubility over that of helium. Projections of these various methods have lead to reports which further indicate limitation will lie somewhere between 1500 and 2500 feet. All indications are that helium as a useful gas from the point of view of narcosis will not seriously limit the diver at depths less than 2,000 feet. Whether this is literally accurate or not remains to be seen and to some degree may depend upon the individual variability of man's susceptibility to inert gas narcosis as well as the presence or absence of other factors which potentiate narcosis.

Other than considerations of the major constituents and physiological active components of the breathing media little previous in depth emphasis has been given to the problem of atmosphere contaminants in trace qualities. Many of the contaminant levels which in shallow or short term diving have appeared to be quite tolerable are now taking on increased importance as exposures progress to several days or even weeks. The human body responds to these contaminants as a function of their partial pressure rather than the percentage composition within the media. Therefore, as the pressure is increased a previously insignificant percentage composition becomes a highly significant value when considered in terms of partial pressure. The classic example of trace contaminants which can become highly toxic is that of carbon monoxide. The toxic levels in a one atmosphere environment have long been recognized and readily avoided in diving operations. This value is generally given at a proportional part of the composition of the breathing media. In reality, however, the actual toxicity of carbon monoxide is not a function of the percentage that appears within the breathing media, but rather a ratio which exists between the partial pressure of oxygen and the partial pressure of carbon monoxide. In deep diving as the percentage of oxygen in the media is reduced to prevent the hazards of oxygen toxicity and a previously insignificant percentage of carbon monoxide takes on a highly significant partial pressure thereby changing this most important oxygen to carbon monoxide ratio. Although it is unclear when dealing with other contaminants whether there is a relationship between the contaminant itself and the oxygen present, it appears far less than speculative that previously insignificant contamination levels of these trace contaminants will become highly significant as the diving depths progressively increase. In many instances analytical methods are currently not available or available only in highly sophistocated laboratories to even determine the concentrations of these various contaminants. Further in many cases the actual toxicity or physiological effects of these contaminants is poorly or totally unknown.

Within recent months renewed and vigorous efforts have been placed on the problem of thermal regulation for the free swimming diver. As diving operations progress deeper and into additional geographic locations where water temperatures approach or reach 29°F it becomes increasingly difficult for the diver to withstand this thermal burden and yet perform useful work. It has long been recognized that it will be necessary to provide external heat to the diver's body to prevent cold injury. Several methods have been developed such as hot water or electrically heated suits. Both of these methods require that the diver be tethered to a source of either electrical power or heated water. Such a tether immediately limits both his range and usefulness. It is certainly hoped that within the next decade a suitable self-contained unit will become available to overcome this perplexing problem. In addition within the last year or two increasing concern has developed over the potential heat loss from the respiratory tract. As gas enters the lungs for the exchange of oxygen and carbon dioxide, it is necessary to elevate its temperature to that of the surrounding tissue. If this gas comes from a cold environment or through a cold environment there is an increased requirement on the upper respiratory tract to provide the energy for this heat transfer. With diving excursions of any duration the potential loss is highly significant. The Navy has recently undertaken a research study to delineate the exact requirements imposed upon the body by this exchange.

Although the immediate requirements for decompression following long term saturation dives appears to be under control, the endpoint used to determine adequacy of decompression remains a subjective report from diver subjects. This implies that decompression is adequate providing no symptoms of pain or other recognizable features of decompression sickness are identified. However, in recent years there has been a growing recognition of the fact that long term disability associated with previous unrecognized decompression sickness can develop. Specific reference here is made to cripping bone changes which have been seen in compressed air workers. At the time of their active diving it appeared their decompression was adequate. However, on subsequent x-ray exam a significant number of these people have demonstrated disabling or potentially disabling bone changes. The best evidence to date indicates this condition of avascular aseptic necrosis has not been associated with Navy diving operations. However, at this reading two SeaLab II subjects have demonstrated the early changes of aseptic necrosis within several of their bones. Therefore, decompression which appeared adequate from a point of view of subjective symptoms may now require some reevaluation. It does not appear that decompression sickness itself will be a limiting factor in man's progression to greater depths for longer periods of time. However, this finding of aseptic necrosis only emphasizes the requirement for better understanding and further development in the art and science of decompression. Saturation diving in this way has made us become more acutely aware of the need to better understand and control the transfer of gas from tissue and determine the exact mechanism behind the development of decompression sickness.

With the advent of long term saturation diving in totally artificial atmospheres of helium-oxygen man again faced a problem which he had conquered in the stone age, that of communication. Due to the properties of this totally artificial atmosphere oral communication becomes quite difficult if not totally impossible. Active efforts on the part of the Navy and private organizations have been expended to solve this most troubling situation. With the use of saturation diving and its expansion to greater depths and far wider fields of endeavor with potentially more acute safety problems and requirement for adequate communication between both the diver and his outside support, as well as between divers becomes paramount. Again the requirement here is for technological advances. It is unlikely that communication from a physiological point of view will become a limiting factor in extending our diving horizons.

Current diving physiology and technique is based on the assumption the body is fluid and therefore non-compressable with the exception of a few air filled cavities. Yet, considerations must be given to the direct effect of pressure on tissue. To date with the limited depths which we have extended man's capability there has been no noticeable effects which can be directly related to hydrostatic pressure. However, it is apparent from some laboratory data that high hydrostatic pressures have many effects which can influence biological processess. Most of these effects are measurable only at pressures far higher than any likely to be encountered by divers, but nonetheless, the subjective sensations of the human diver in his performance measured by psychological tests are so exquisitely sensative and involve such a tremendous series of complicated reactions that any slight abnormality may be readily detected. However, it does not appear unless man can learn to breathe liquids at high pressures whether the direct hydrostatic effect of pressure will become limiting.

The really exciting aspects of saturation diving are seen when one projects the potential applications of this technique to military requirements and operational needs. At this time the borders of conception lie where man will be able to exist in the sea's environment itself as does the fish. For the present rather it is necessary to consider his requirements while he performs work using the technique of saturation diving. Therefore, foremost he must have a habitat or container to which he can return following his working excursion dives. This house can take on several different forms one being the floor mounted habitat such as demonstrated by SeaLabs I and II, a deck decompression chamber mounted aboard a support ship such as utilized in the Mark I and Mark II diving systems, or a mobile underwater platform such as a submarine with the ability to lock a diver in and out while maintaining one portion of the ship at or near pressure equilibrium with the surrounding environment. Each of these methods has definite application to present requirements and operations. The choice depends on a multitude of factors such as bottom topography, surface conditions, operational or military objectives and presence or absence of hostile activity. Within the next 10 years it is highly conceivable that the Navy's diving capabilities will extend to or beyond 1500 feet therefore, affording us the expanse of the Continental Shelves and upper continental slope for further exploration and military applications.

At the present time we see the use of saturation diving for salvage operations utilizing the technique of a deck decompression chamber and a submersible decompression chamber for transfer of divers to and from the wet environment. The Mark I and II diving systems should make such salvage operations routine within the next year. Salvage which previously could not be performed by surface supported divers operating on a day-to-day basis will now be within our grasp on a near to routine. At the same time it can be readily seen that construction and maintenance will similarilly be possible. Whether this construction be a large hydrophone array for surveillance of shipping activity, a research station to perform oceanographic and marine biological investigations or the permanent installation of underwater missile systems. The applications to undersea warfare remain almost unlimited. Manned or unmanned ocean floor installations in friendly or hostile waters which maintain surveillance on harbor and shipping traffic and facilities appear to be available within out immediate future. A mobile platform with the ability to lock divers in and out to provide logistic support for amphibious assaults or to neutralize enemy harbor and shipping facilities contained within those waters. One can readily imagine a submarine maintenance facility located within either a bottom floor mounted structure built for that purpose or located inside an underwater cliff which can service or support our expanding nuclear fleet would provide the facilities to make the nuclear submarine the absolutely true underwater vehicle. At present although the ship is provided with capabilities to stay underwater for prolonged periods of time it still must return to the surface for re-supply and logistic support. With such an underwater station this last tie with the surface would be minimized.

The ability to remain deep under the surface and perform useful operations is one of the principal advantages of saturation diving technology. A feature of this capability which is of prime importance to the military application is for controlled convertness. Therefore, a matrix which incorporates this aspect at one extreme, where operations must remain hidden or be performed serreptitiously, to the opposite extreme, where operations may be performed in full view, are all within the realm of saturation diving.

At the present time the limited use of saturation diving as a useful military tool are not related to the physiological boundaries of the diver but rather to limits of an engineering and technological nature. In order to obtain the full advantage of this technique various systems must be developed in support of basic saturation diving. Included in this list would be new and improved types of losed circuit breathing apparatus, divers communication and navigation assistance, better thermal protective suits and thermal conservation equipment, new, fast methods for construction and mobility of undersea installation, and swimmer delivery vehicles which expand the operating range of divers while in the environment of the sea.

In summary it can be safely stated that the technique of deep saturation diving is presently available for nearly unlimited military application and its usefulness is only bounded by the imagination of those that choose to employ it. There would appear little doubt that the development of this concept has nearly insured an operational capability of 2000 feet by 1980.

SATURATION DIVING FROM LESSER DEPTH HABITATS

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ABSTRACT

The scope of underwater operations made possible by saturation-excursion diving techniques has not yet been fully appreciated by the U. S. Navy, although it will have four saturation diving systems operable in a little more than 12 months. A nitrogen-oxygen saturation system is described and its advantages pointed out for diving tasks in the lesser depth ranges (to 250 feet). A transport submarine is already available for operations with a one-atmosphere habitat placed on the ocean floor at 2000 feet or deeper.

Saturation diving is the only method by which extensive diving operations beyond the shallowest depths can be conducted. This concept has been known to relatively few theorists over a period of the past 50 years. However, it was just five years with SEALAB II that Captain George F. Bond completed his demonstration that saturation diving is a practical procedure for the U. S. Navy. (4) In the few years since that time the Navy has developed completely new Deep Diving Systems, component equipment and procedures with which to conduct saturation diving operations. Under the direction of the Deep Submergence Systems Project (PM11) in the SEALAB and Man-in-the-Sea programs the Navy has accomplished 2000 man-days under pressure in saturation dives from 100 to 1000 feet. Two Deep Diving Systems (DDS) Mark 2 are under construction for installation on board the Navy's new catamaran hull submarine rescue vessels, USS PIGEON (ASR 21) and USS ORTOLAN (ASR 22). A prototype DDS Mark 2 has already been installed for test and training on board the San Clemente Range vessel USS ELK RIVER (IX 501). The Supervisor of Salvage has also developed a lesser capacity, modular, air transportable DDS Mark 1 and this system is presently undergoing evaluation at sea together with PM11's new umbilical supplied semiclosed circuit helium-oxygen deep diving apparatus Mark 11.

Saturation diving is no longer the impractical concept of a Navy dreamer. It is now not even strictly in the Research and Development stage. Starting this summer, and continuing over the year to come, the Navy will receive four new operational Deep Diving Systems which will all be capable of supporting saturation diving. But the Navy has not yet begun to appreciate what this new capability will make possible for accomplishment in underwater operations. Diving is still visualized by the non-diver as essentially a dunking operation. The diver plummets to the bottom and loiters for a moment only. He picks up a small object, shackles a chain, turns a valve, or drops a flag; and then must begin his slow, cold, tedious ascent of decompression back to the surface. The Navy's new Deep Diving Systems have not simply made this depressurizing confinement slightly less uncomfortable for the heroic diver (who would then of course be required to dive deeper and tolerate even longer decompressions); they have made possible underwater operations of truly industrial proportions at any continental shelf depth. Still the nature of the ocean and of man's diving is such that these tasks will be larger and more numerous at shallow and intermediate depths than they will be at the extreme.

Some glimmer of this is becoming evident in the saturation operations of the commercial diving industry, particularly in the off-shore oil fields of the Gulf of Mexico. These companies are laying, welding and inspecting miles of new pipe lines in round-the-clock industrial operations employing both deck saturation chambers and underwater working habitats at depths to date down to approximately 300 feet. They utilize technology and procedures freely adopted from the Navy's work in the Man-in-the-Sea program and

Superior numbers in parentheses refer to similarly numbered references at the end of the paper."

even hire ex-Navy personnel who had been trained in saturation diving at the Experimental Diving Unit and the Deep Submergence Systems Project Technical Office during the years of development in preparation for SEALAB III.

In response to its charter the Deep Submergence Systems Project chose to develop a saturation diving system which operates principally using helium-oxygen breathing mixtures. Only through the use of helium diving is the capability to dive to all continental shelf depths possible of attainment. We have yet to find the ultimate depth to which this type of diving is limited, and it can also, of course, operate as shallow as is desired or practical. Although PM11 quickly found its hands full with all the problems of mastering helium technology, it had sidestepped deliberately the considerable problems of nitrogen technology and physiology which are involved in saturation diving with nitrogen-oxygen breathing mixtures. Although nitrogen-oxygen saturation diving has many attractive elements, especially simplicity and economy, and is being successfully investigated, its exposures will probably be limited to depths of 100 feet or less.

In the spring of 1969 the Office of Naval Research directed U. S. Navy efforts, together with those of the Department of the Interior, the National Aeronautic and Space Administration (NASA), and the General Electric Company in the conduct of Project TEKTITE I, which was a sixty day nitrogen-oxygen shallow saturation dive. (5) The habitat for this project was placed at a depth of 47 feet on the bottom of Greater Lameshur Bay of St. John Island in the Virgin Islands National Park. Since the habitat's open lowermost hatch was six feet above the bottom, its interior pressure was equalized to a gauge depth of 41 feet of seawater or 2.2 atmospheres absolute (ATA). Although this was a nitrogen-oxygen dive, compressed air was not used in the rigorous sense. The habitat was pressurized initially with compressed air, but pure nitrogen was subsequently added to adjust the proportion of gases in the atmosphere to approximately 90% nitrogen and 10% oxygen. Thereafter additional compressed air was added to the habitat atmosphere at an average rate of 16 to 24 standard cubic feet per hour, but this flow did not substantially alter the gas proportions stated. Since the habitat was open to the sea and equilibrated to seawater pressure at the lowermost hatch, a nearly equivalent volume of habitat gas was exhausted through vents in the entrance trunk as the compressed air was being added. (A small volume of gas had to be added or vented in a similar fashion to compensate for the pressure fluctuations induced by tidal variations.) The total flow of air was sufficient to maintain the oxygen partial pressure of the habitat interior at approximately 160 torr (millimeters of mercury). The rate of flow was manually controlled but was based on measurements of the actual PO_2 level in the habitat. When the metabolic consumption of oxygen by the four Aquanauts had dropped the oxygen partial pressure to 150 torr, then low pressure blowers on the surface were started to pump compressed air into the habitat. When this addition had been sufficient to raise the oxygen pressure to 165 torr, then the blowers were stopped.

This limited ventilation was designed to replace only the oxygen removed by the diver's metabolic consumption. It was not sufficient to carry away the carbon dioxide produced by them in the same metabolic process. Another life support system was necessary in which the habitat gas was continuously recirculated through an absorbent bed of chemical Baralyme to remove carbon dioxide.

Four scientist Aquanauts lived in the pressurized habitat for sixty days and were able to make diving sorties from it into the water of Lameshur Bay ranging from depths as shallow as 22 feet to as deep as 85 feet and swimming as far as 1500 yards from the habitat. These excursions were all made from the saturated pressure of 41 feet. Over their entire 60 day stay the four Aquanauts spent 432 man-hours in the water for a team average of 7.2 man-hours per day. Toward the end of the project, however, individual divers were spending 5 hours per day in the water.

The simpler logistics and economy of this diving system make nitrogen-oxygen saturation diving appealing, especially to those whose diving interest is focused on long duration tasks in the first hundred feet of depth. A good many oceanographic scientific investigations fall into this category. (3) A follow-on Project TEKTITE II has already been commenced and will run throughout this summer at the same Virgin Island site. The management agency is now the Department of the Interior. NASA and GE are again deeply involved in the Project, but Navy participation has been limited. This year's program calls for more extensive operations at last year's depth, 50 feet, but plans have been included for separate operations as well in a smaller habitat placed at a depth close to 100 feet. The atmosphere will still be compressed air enriched with additional nitrogen. The oxygen partial pressure will be controlled close to 0.2 ATA, which is the pressure of oxygen in this room, but the pressure of nitrogen will be elevated by a factor of almost five. Because of the problem of nitrogen narcosis and the difficulty of maintaining adequate respiratory ventilation while breathing dense compressed gas, 100 feet is felt to be near the depth limit for extended saturation exposures with nitrogen. These problems are not restrictive for shorter dives. Several European navies claim a capability to make short working dives to 250 feet. Divers of the U. S. Navy were successful in making working compressed air dives to salvage the submarine F-4 from a depth of 300 feet near Honolulu in 1915. However, in 1939 considerable difficulty was experienced with air dives in cold water to a depth of 240 feet, and helium-oxygen dives were thereafter used for the salvage of the SQUALUS (1).

The oxygen pressure of a long term exposure can safely be permitted $2\frac{1}{2}$ times higher than the TEKTITE level. However, since the nitrogen effects will ultimately determine the limit for this type of diving, the TEKTITE dives have been purposely constructed around the investigation of nitrogen and carbon dioxide physiology in the saturation diver. It has been for that purpose that the highest nitrogen partial pressure was selected.

Even if nitrogen-oxygen saturation exposures are limited to depths no greater than 100 feet, through the use of no-decompression excursion techniques the depth range from 100 down to 250 feet is also open to nitrogen saturated divers. Depending upon the depth and other characteristics of the diving task, the breathing mixture used in the underwater breathing apparatus of the excurter could be nitrogen-oxygen or air for the shallowest depths, helium-oxygen for the deeper jobs, and possibly a tertiary mixture of nitrogen-helium-oxygen for the intermediate depth range.

In the SEALAB experiments and in the chamber saturation dives which were made in preparation for them, the focus of most early investigations was upon the effects of the saturation exposure itself. To reduce the number of variables involved, the dive was made to only one depth at a time. In the popular conception saturation diving came to mean extended exposures at a single depth with the diver, even in the water, remaining fairly close to this saturation depth. However, if one thinks of life at sea level as a saturation exposure to nitrogen-oxygen at a total pressure of one atmosphere absolute, then normal diving from sea level is really "excursion" diving from a saturated exposure. When the diver excourses, his tissue inert gas tensions will increase. When he returns to the saturation pressure, these tensions will be reduced toward the equilibrium level. This is the same situation in "excursion" diving from any saturation depth as it is in diving from the surface. However, the magnitude of the no-decompression excursions permitted under these circumstances will increase as the pressure of the saturation exposure increases. The following examples will illustrate the point: (2, 6, 7)

1.	BOTTOM TIME FOR NO-DECOMPRESSION AIR EXCURSION 50 FEET DEEPER THAN AIR SATURATION EXPOSURE AT SURFACE	100 MINUTES
	BOTTOM TIME FOR NO-DECOMPRESSION AIR EXCURSION 50 FEET DEEPER THAN AIR SATURATION EXPOSURE AT 50 FEET GAUGE	8 HOURS
2.	BOTTOM TIME FOR NO-DECOMPRESSION HELIUM-OXYGEN EXCURSION 80 FEET DEEPER THAN AIR SATURATION EXPOSURE AT SURFACE	60 MINUTES
	BOTTOM TIME FOR NO-DECOMPRESSION HELIUM-OXYGEN EXCURSION 100 FEET DEEPER THAN HELIUM-OXYGEN SATURATION EXPOSURE AT 150 FEET GAUGE	60 MINUTES

BOTTOM TIME FOR NO-DECOMPRESSION HELIUM-OXYGEN EXCURSION 150 FEET DEEPER THAN HELIUM-OXYGEN SATURATION EXPOSURE AT 300 FEET GAUGE	60 MINUTES
3. BOTTOM TIME FOR NO-DECOMPRESSION HELIUM-OXYGEN EXCURSION 100 FEET DEEPER THAN AIR SATURATION EXPOSURE AT SURFACE	35 MINUTES
BOTTOM TIME FOR NO-DECOMPRESSION HELIUM-OXYGEN EXCURSION 100 FEET DEEPER THAN HELIUM-OXYGEN SATURATION EXPOSURE AT 150 FEET GAUGE	60 MINUTES
BOTTOM TIME FOR NO-DECOMPRESSION HELIUM-OXYGEN EXCURSION 100 FEET DEEPER THAN HELIUM-OXYGEN SATURATION EXPOSURE AT 300 FEET GAUGE	100 MINUTES

Let me emphasize, lest I be misunderstood, in excursion diving from any fixed saturation depth, as well as from the surface, the maximum bottom time which will still permit a no-decompression return to the depth of the saturation exposure will decrease as the difference between excursion depth and saturation depth increases. The maximum permissible no-decompression bottom time will increase as the excursion depth is closer to the saturation depth. But the excursion tables will expand as the depth of the saturation exposure from which these dives are made is made greater. (2)

A diver is sent underwater to complete a specific task. In saturation diving operations, no less than in any other, the diver may be required to move up and down in depth, due to irregularities in bottom topography at the work site, due to the need to scale man-made structures on the bottom (such as the oil towers demolished by Hurricane Betsy in the Gulf of Mexico), or simply out of a desire to achieve the economies of decompression which are possible with excursion diving. It is also characteristic of saturation-excursion diving that it is possible to move the depth of the saturation exposure deeper, and closer to a fixed working depth, if more no-decompression excursion time is desired. It has always been easier, as well, to develop limits for no-decompression diving than it has been to formulate universally adequate schedules for dives which do require decompression.

The suggestion has been made that an ideal saturation diving vessel could be constructed along the lines of present Navy submarines by designing the two forward compartments into a pressurized habitat. Such a vessel would be free of surface weather effects and could operate without the obvious visibility of surface support elements. These suggestions become more realistic in cost-effectiveness if a nitrogen-oxygen saturation diving system is considered. Some major consumables such as Baralyme will always be required, but most of the gas requirements of the nitrogen-oxygen systems could be met with a modified snorkel in a diesel submarine. The ship should be as small as possible for the shallowest operations, but use of the saturation-excursion techniques would permit divers from this system to operate down as far as a depth of 250 feet.

One final situation which I would like to discuss before I conclude is that of one atmosphere habitats deeply placed underwater. The Naval Facilities Command, working with SEALAB and TEKTITE as well as with its own programs, is developing the capability to construct underwater structures. If saturation diving techniques are necessary for this work, the SEABEES intend to be ready. As our undersea electronic arrays become more complex and extend further from land-based headquarters, it is conceivable that dry bottom structures would be desirable for electronic substations. Their internal atmosphere would be air at surface pressure, and this gas environment would present as few physiologic problems as our simplest present submarines, especially if the habitat is not occupied full-time, but simply visited regularly for replenishment, inspection, and maintenance. An overhead submarine hatch in this structure would provide a mating surface for the transport submersible which brings the maintenance crew to their work. This transport vehicle is already available. The first Deep Submergence Rescue Vehicle (DSRV) was launched last January and the second DSRV is scheduled for launching this fall. These submersibles can carry 24 passengers, are capable of operating to a depth of 5000 feet and can accomplish dry transfer in water depths as great as 2000 feet. A future requirement for a deeper transfer depth has been anticipated, and it would involve only retrofit of a stronger transfer skirt to make this possible.

How deep could we go with these structures? If divers are required for construction, 1000 foot saturation dives are entirely feasible. The very recent successful 1500 foot chamber saturation dive at the Royal Naval Physiological Laboratory in England points out the likelihood that saturation diving operations at 2000, or even 3000, feet are also possible. It is also likely that such structures could be built and emplaced without diver support. The Oakland-San Francisco tunnel of the Bay Area Rapid Transit system was assembled without caisson work and with minimal diver involvement. Sections were constructed in a shipyard with blanked off ends. After launch they were floated to the tunnel site where they were precisely located and sunk. Hydraulic mechanisms pulled the ends together to make an underwater seal until the final connection could be joined. Bulkheads were then removed from the connecting ends to link the adjacent tube sections. Could a similar system be made to work in the deep ocean?

Naval operations are moving increasingly underseas. The basic diving systems for supporting this move will shortly be available. Further development can take several directions, and the choice will depend upon the uses you intend to make of the equipment which will soon be delivered to you.

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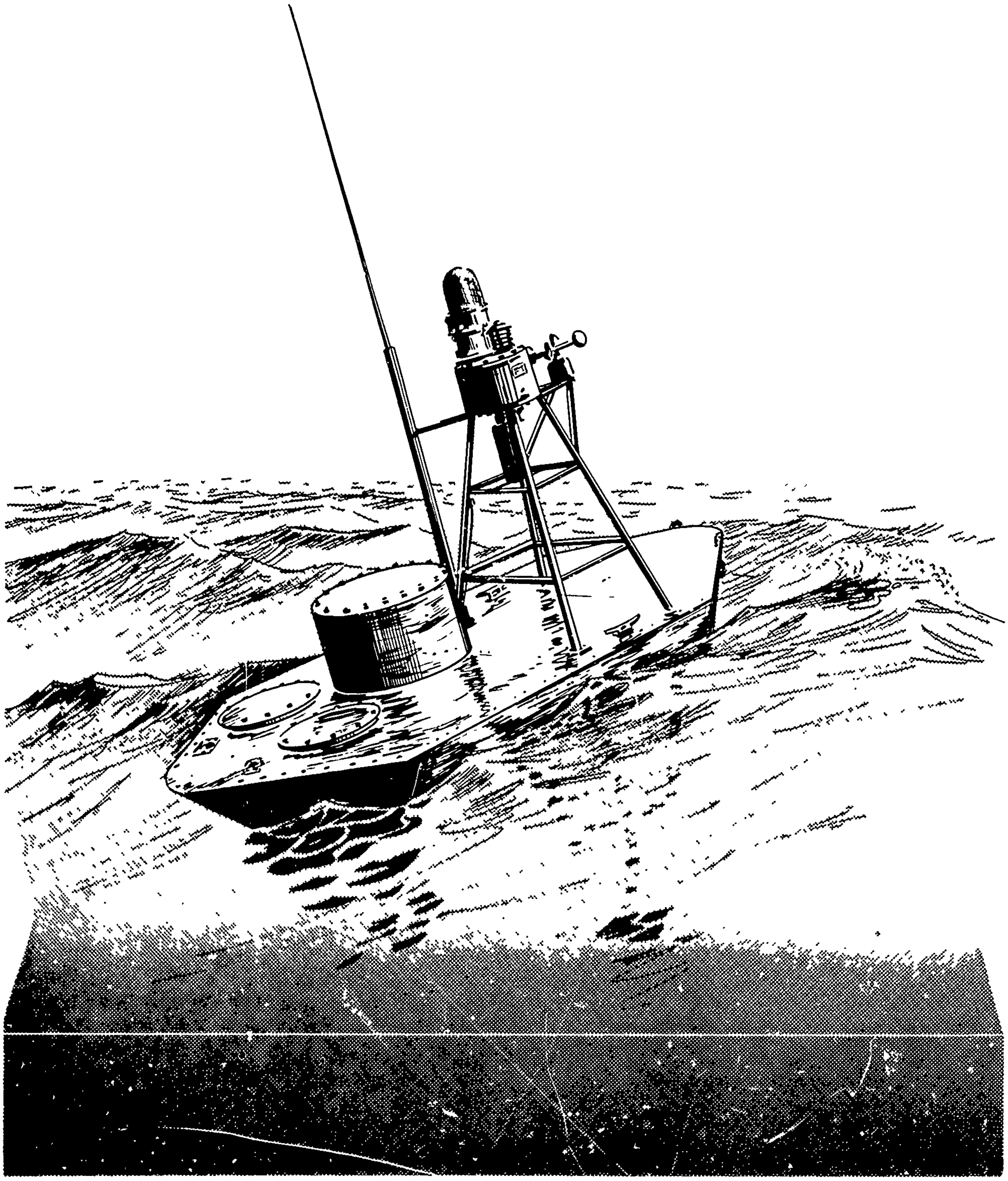
Knowledge for Prediction of the Sea



OPERATIONAL OIL SPILL DRIFT FORECASTING

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ABSTRACT

Recent incidents of large scale oil pollution have had catastrophic effects on the ecology, recreation and wild life resources of coastlines and coastal waters and caused worldwide public opinion to be very sensitive to this problem. Fleet Weather Centrals should have the capability to provide movement forecasts for oil spills from naval vessels or other sources, identifying the area of maximum threat and permitting containment action to be taken most efficiently. A tentative method is presented using surface current parameters based on operational data available at most Navy Fleet Weather Centrals.

The surface current parameters influencing oil spill drift used in this proposed forecast method are permanent currents, wind drift, geostrophic and tidal currents. A basic operational forecast using the vector sum of the pertinent parameters is presented. Modifications of the basic forecast method due to the location of the spill (open water, restricted water) are explained. The method presented should provide an acceptable forecast as an aid in effective control or containment of oil spillage.

INTRODUCTION

Recent incidents of large scale oil pollution have had catastrophic effects on the ecology, recreation, and wildlife resources of large areas of coastlines and coastal waters. Increased awareness of the pollution problem has caused worldwide opinion to be very sensitive to any form of unnecessary or preventable pollution. While the "Torrey Canyon" and "Santa Barbara Channel" incidents have received credible infamy becuase of their magnitude, increased offshore exploration and oceanic transport of oil by merchant and navy vessels add to the possibility of more incidents of pollution. Spillage of oil cannot be foreseen, but if it does occur and coastal areas are endangered forecasting the movement of the slick can be an invaluable aid in identifying the areas of maximum threat and in permitting the most efficient method of containment to be utilized. Fleet Weather Centrals should have the capability to provide movement forecast for oil spills from naval vessels or other sources.

In this paper, the authors present an operational method of forecasting oil spill drift using data available to Fleet Weather Centrals. Surface current parameters influencing oil spill drift used in this forecast method are tidal currents, permanent currents, geostrophic currents, and wind drift currents. Each of these parameters will be discussed and the contribution of each to the forecast method using their vector sum will be explained. The basic format can be modified as necessary for use in restricted or open waters.

DEVELOPMENT OF THE FORECAST

Tidal currents are considered only near coastlines or in restricted waters. Offshore tidal influences on the drift will be negligible. The influence of tidal currents is determined by the proximity of the coastline, the depth of the water, and, possibly, the size of the spill. The magnitude of the current is determined from tide and current tables. Modification may be required by data from Fleet Guides and local climatology.

A forecast of the tidal component is made using a time period in hours and the average value of the tidal currents. Average values of both ebb and flood currents are used since they are not necessarily in opposite directions or have the same magnitude. The tidal component of the oil movement (D_t) is:

$$\overrightarrow{D_t} = \sum\left[\overrightarrow{(C_e T_e)} + \overrightarrow{(C_f T_f)}\right], \qquad (1)$$

Where

C_e is ebb current,

C_f is flood current,

T_e is total hours ebb current occurs in forecast period,

T_f is total hours flood current occurs in forecast period.

Permanent currents are constant features being the average currents that normally exist in the forecast area. This component is the most important in regions of regular strong currents such as the Florida Current, Gulf Stream, and Labrador Current. This component would be negligible in many areas of the open ocean such as near the center of circulation gyrals. One source of permanent current values is NAVOCEANO Publication No. 700. Permanent currents are designated C_p.

The classic formulas for computing the geostrophic current are much too complex for operational use. We need something that is fast and simple but still reasonably accurate. Figure 1 from James is a graph derived from actual cruise data of horizontal temperature gradient versus current for three areas of the Western Atlantic. The curves were based on best fit of scattered data. Since actual data was used in their derivation the curves include salinity effects. Movements will be parallel to the isotherms.

Wind drift currents are probably the most important single factor contributing to the movement of oil spills except near the cores of permanent currents. The greater viscosity of oil retards wave development. Therefore, somewhat less energy is transferred from the wind to the surface of oil than to water. For convenience we will assume that there is no difference. A relationship between wind velocity and surface current was expressed by Ekman as

$$\frac{V}{W} = \frac{0.0127}{\sqrt{\sin\phi}} \qquad (2)$$

where V is surface drift current

W is wind speed

ϕ is latitude

at 40° North the relationship would be V = 0.0157W. The fraction 0.0157 or 1.57 percent is the wind factor. Thus the wind drift current would be 1.57 percent of the wind speed. The wind factor has been calculated by many. All the computations of wind factor fall between 1.00% and 4.5%.

In figure 2, James presented wind drift forecasting curves relating wind drift currents to wind velocity, duration and fetch. For operational use, obtaining wind drift current from the graph is acceptable. Although the angle is debated, according to James, evidence indicates, in general, that the drift current will be 20 degrees to the right of the wind direction in the Western North Atlantic. Assuming that the surface wind is 20 degrees to the left of the geostrophic wind, we can then assume the drift current is parallel to the isobars on the surface weather map. We will use the symbol $\vec{C}_{wd}$ for the wind drift current.

Either the wind factor formula or the wind drift forecasting curves will give satisfactory estimates of wind drift. The advantage of the curves is that they can be used when there is a change in wind speed. The curves also allow consideration of fetch and duration of the wind.

Having obtained each of the current components we can determine the net displacement of the oil slick by computing the vector sum of the components as shown in figure 3.

$$\vec{D} = \sum(\vec{D}_t + \vec{C}_pT + \vec{C}_gT + \vec{C}_{wd}T) \qquad (3)$$

where T is the time interval of the forecast.

As shown in figure 3, the net displacement is simply the vector sum of the pertinent parameters. The individual vectors are determined and from these the resultant vector is drawn indicating the direction and magnitude of movement of the spill.

MODIFICATIONS

In deep water, well offshore, the influence of tidal currents can be considered negligible. In open water the time interval before a threat to land exists would be large and a greater time interval for the forecast can be used. Thus, any tidal influences will be either negligible or have a net effect of no movement. In this instance, $\vec{D}_t$ can be omitted from the forecast formula.

In restricted waters tidal currents and directions must be considered closely. Ebb and flood currents may not always be in opposite directions or equal in magnitude. Under such conditions shorter time intervals for the forecast may be required. Generally, in shallow restricted water permanent currents may be considered negligible. River and fresh water outflow must be considered along the coasts. They can be considered as a separate vector in the forecast equation.

Geostrophic currents can be considered negligible in restricted water or in shallow water of less than 100 feet.

In regions of strong permanent currents, i.e., Gulf Stream, we do not differentiate between geostrophic and permanent currents. Where large meanders in the permanent current are indicated by the sea surface temperature pattern it may be advantageous to use the geostrophic current rather than the climatology based permanent current. Away from these areas, existing conditions (sea surface temperature pattern) may be such that a geostrophic current can be established in addition to any permanent current derived from current atlases. In this case a geostrophic current vector must be applied to the drift formula.

The forecast would attempt to predict the position of the leading edge of the oil slick. If a wind shift significantly changes the direction of the movement of the oil a new leading edge would result requiring a modification of the forecast.

If the oil originates from a continuous source such as an offshore well or continuous leak from a large tanker the problem would be more complicated than with a single small "puddle" of oil. In this case forecasts at several points along the leading edge of the slick would be necessary. The complicity of the forecast depends on the size of the oil leak, direction of movement, and changes in the direction of movement due to wind shifts or current patterns.

Longshore current must be considered once the oil reaches the coastline. The forecast of longshore currents would depend on the character of the beach and existant surf conditions.

CONCLUSIONS

A much more complex method could be conceived using more detailed mathematical models. Such a method would, undoubtedly be more accurate. However, the accuracy of input data available for some of the parameters is questionable. In open water recent measurements of input data may be sparse or not available. In restricted waters local effects may predominate and movement of the leading edge due to dispersion is difficult to measure. The forecast method is intended to be flexible enough to fit the situation and simple enough to be used readily and rapidly. The requirement for such a forecast would be unexpected and would probably be needed immediately. This would leave little time for lengthy calculations. A simple yet reasonably accurate forecast based on data immediately available can be made quickly when it is needed and time is critical. While this method is, indeed, simple it is meant for use on an operational basis. It will provide an acceptable forecast that can contribute to planning, and assist in effective control and containment of an oil spill.

ACKNOWLEDGEMENTS

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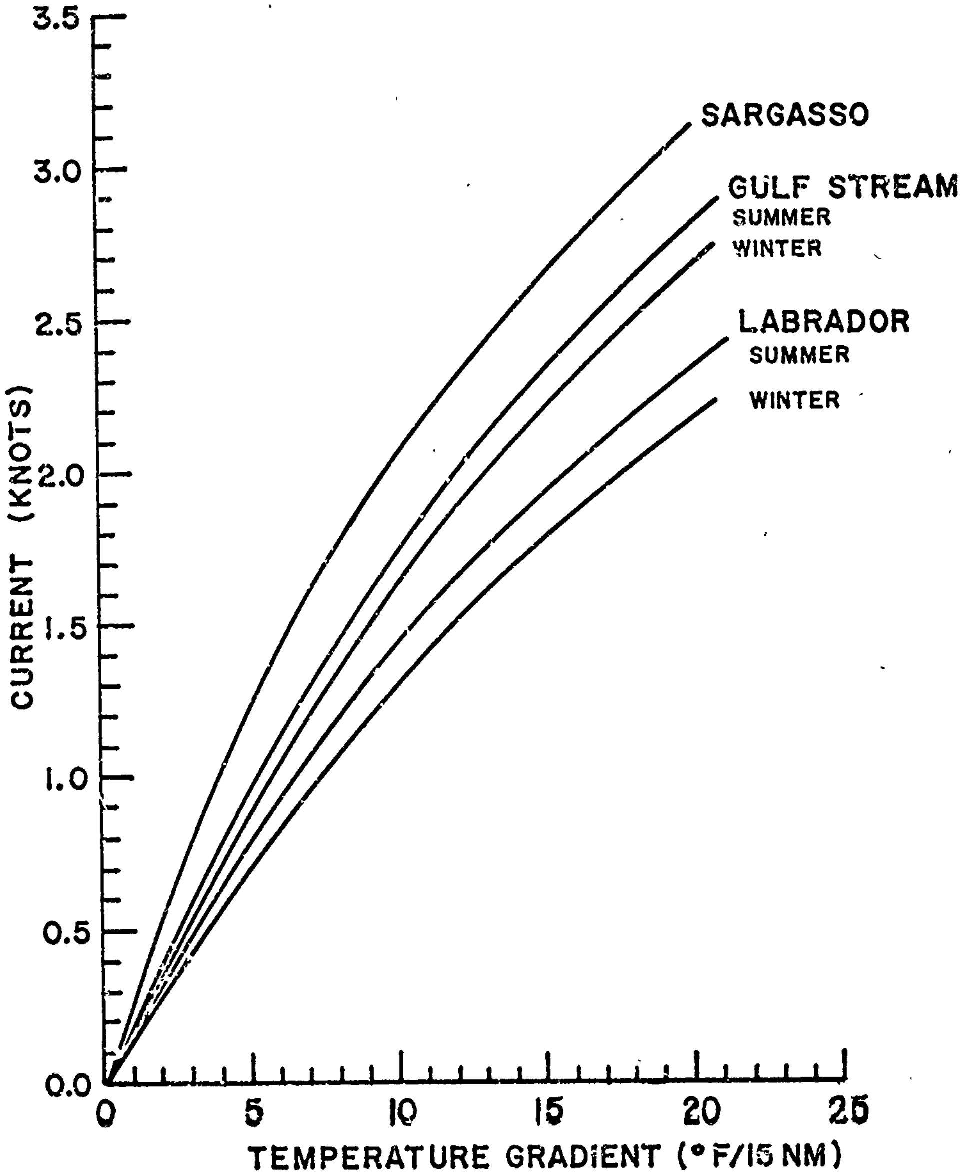

FIGURE 1

Estimation of Geostrophic Currents

(After James)

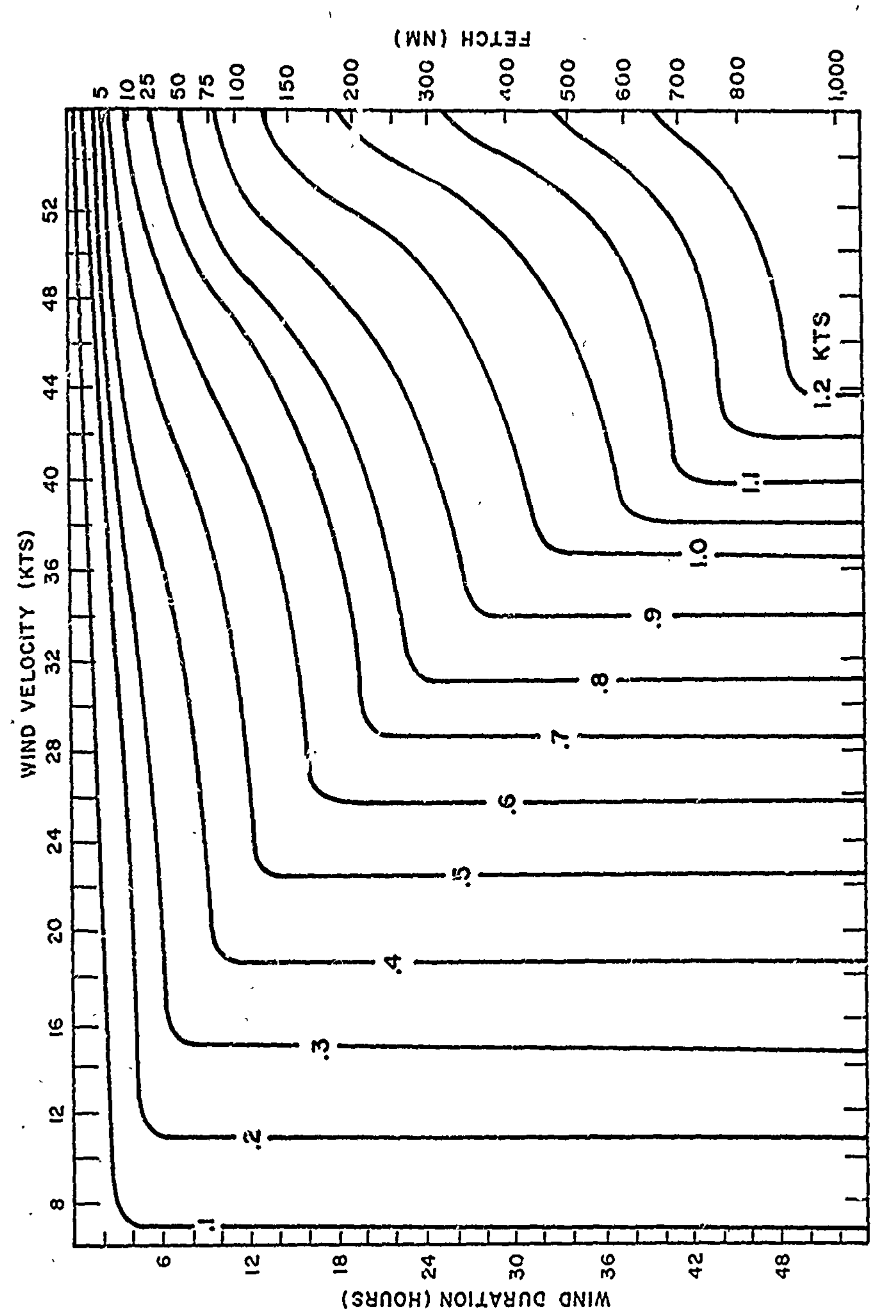

FIGURE 2
Wind Drift Currents (Kts)

(After James)

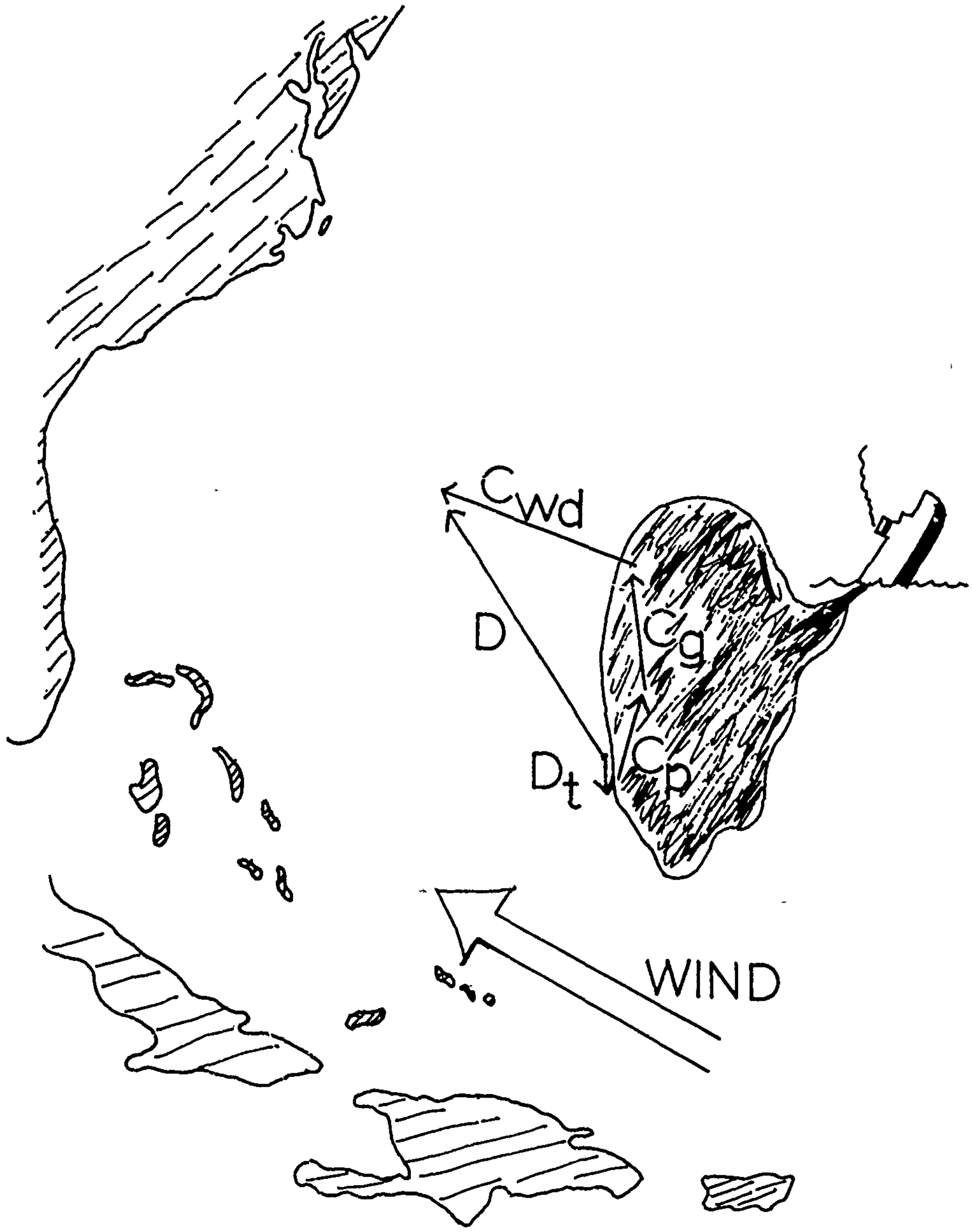

FIGURE 3
EXAMPLE OF VECTOR
SUM

THE PLANNED OPERATIONAL USE OF SATELLITE DATA IN DERIVING SEA SURFACE TEMPERATURE INFORMATION FOR NAVAL OPERATIONS

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ABSTRACT

The use of radiance measurements from satellites for deriving sea surface temperatures is briefly summarized. The problem of cloud contamination and corrections to the derived equivalent blackbody temperatures are discussed. Operational data-handling is treated with emphasis on the plans for the handling and use of data from the ITOS-1 meteorological satellite to be transmitted via the Naval Environmental Data Network (NEDN).

A primary parameter in forecasting the maritime environment is the mean temperature of the water in the first few feet below the ocean surface. Commonly called "sea surface temperature" (SST), this parameter has wide use in Naval applications and immense potential in national economic benefit. While the Naval Weather Service currently analyzes sea surface temperature for its application to antisubmarine warfare, it also has application in atmospheric measurement and prediction and commercial fishing. Several authors, such as Namias[1] and Smagorinsky[2] feel that the ability to accurately derive the SST could ultimately improve our ability to provide long-range weather forecasts. The SST would be used in obtaining air-sea heat exchange information for input into large-scale diabatic numerical prediction models. The report of the study conference on "The Global Atmospheric Research Programme (GARP)"[3] stated the requirement for SST accuracies of $\pm$ 0.25°K for air-sea interaction studies.

The U. S. Navy Fleet Numerical Weather Central (FNWC) at Monterey, California, routinely produces an operational sea surface temperature analysis. This analysis is the basic product in FNWC's oceanographic library. The accuracy and resolution of these SST fields are limited by the distribution of oceanographic data. Ships at sea, including Navy ships, tend to follow well-established trade routes between points, as shown in Fig. 1.[4] Note the vast expanses of ocean which may go for months -- or perhaps years -- before having their sea surface temperature sampled. For purposes of weather prediction, this sampling problem is particularly acute, since those areas of potentially high interest for severe weather forecasting are often avoided by shipping.

Anticipating the operational availability of radiometer data from satellites, the Naval Weather Service initiated a program to provide for satellite input into existing SST analyses. The goal is to have an operational program using the data from ITOS-1. This effort is not unique. Several investigators have been working on the problem of utilizing thermal radiance measurements from polar-orbiting satellites to derive sea surface temperatures.

Recent results obtained by Warnecke, McMillin and Allison[5] from observations of the NIMBUS II scanning High Resolution Infrared Radiometer (HRIR), found that sea surface temperatures derived using the HRIR sensor compared well with observations from low-flying, radiometer-equipped aircraft, provided certain corrections were applied.

Superior numbers in parenthesis refer to similarly numbered references at the end of this paper.

These corrections included one for atmospheric attenuation, one for the so-called "micro-surface effect" and one for the deviation of the sea surface emissivity from unity. These corrections were found to average 3° or 4°K.

LaViolette and Chabot[6] studied the use of HRIR in SST analysis and attempted to minimize cloud contamination in partially cloudy regions by selectively compositing several days of HRIR data. Their technique involves examining the test region in detail for five consecutive days and combining the results in a High Daily Average (HDA) composite. The five-day HDA composite is obtained by comparing the daily temperature average at a "point" for each of the five days and selecting the value corresponding to the highest daily average which occurred during the five-day period. This procedure was repeated for all grid points to produce HDA sea surface temperature.

Curtis and Rao[7] attacked the cloud contamination problem by using the highest measured temperature value within half-degree latitude/longitude rectangles. Where breaks occur in cloudy areas, the highest values should correspond with sea surface observations through those breaks.

Greaves, Willand and Chang[8] studied techniques for optimum data processing to provide analysis methods for routine operational measurement of sea surface temperature patterns. In pursuing the cloud discrimination problem they followed a two-phase approach in utilizing data from Nimbus II. They used HRIR data (3.5 to 4.1 microns) for the derivation of SST after having used the Medium Resolution Infrared Radiometer (MRIR) data to discriminate clouds. Automated day and nighttime cloud discrimination and composite mapping programs were developed for the Nimbus data, although little oceanographic interpretation was made of the analyses.

Tilden, Clark and Holl[9] developed the analysis used in the U. S. Navy operational mapping of sea surface temperature. This program uses a mix of satellite-derived temperature gradients and conventional observations, combined by using the "Fields by Correlation Assembly" (FCA) technique reported by Danard, Holl and Clark.[10] The FCA is a blending operation whereby mutually independent observations are compounded by spatial propagation through gradient and Laplacian information. A feature of the FCA technique is that it allows for weighting the information according to its reliability before deriving a combined analysis. An important strength of the FCA method, especially considering the ever-present cloud contamination problem, is that it provides an "estimate of reliability" chart along with the primary product, the SST chart. Both charts benefit a field user by providing him with a measure on which to base confidence in the SST field. The impact of cloud contamination can be assessed by a user, since the cloud contaminated areas tend to show up as areas of low reliability.

There are three major problems (two of which have already been mentioned) associated with operational sea surface temperature analysis utilizing meteorological satellite data:

(1) Cloud contamination of the measurement of sea surface radiance.
(2) Atmospheric attenuation of the sea surface radiance.
(3) Data handling and processing.

To attack the cloud contamination and the data handling problem, Tilden et al[9] developed an empirical technique based on the 3.5 to 4.1-micron radiance measurements converted to equivalent black body temperatures. Working with a full-resolution 2048 X 2048 mapped polar stereographic projection array of the Northern Hemisphere, tests were run using full, quarter and sixteenth resolution arrays. Considering all aspects of the problem of establishing an operational system, a quarter-resolution array (512 X 512) appeared to be optimal. Sixteen points of the 2048 X 2048 full-resolution array surrounding each point of the 512 X 512 array are screened. The highest temperature is selected to represent the grid point value in the reduced array. After this, cloud contamination screening is accomplished as follows:
(1) Large cloud systems are removed by rejecting all values which are colder than

the previously analyzed field by a certain amount, ΔT, at the equivalent location; (2) intermediate-scale cloudiness is removed by applying a finite difference Laplacian smoothing operator to the data; (3) small cloud elements are removed by a gradient check in which all spots more than one degree colder than any one of four neighboring spots are discarded; (4) residual contamination is minimized by rejecting all spots which do not have at least one neighboring point.

Given a cloud-free spot, the radiation sensed by the satellite-borne radiometer can be expressed by the familiar radiative transfer equation:

$$E = \frac{1}{\pi}\int_{\lambda_1}^{\lambda_2} \phi(\lambda)\tau_S(\lambda)\varepsilon_S(\lambda)\beta(\lambda,T_S)d\lambda$$

$$+ \frac{1}{\pi}\int_{\lambda_1}^{\lambda_2}\int_{0}^{\infty} \phi(\lambda)\frac{\partial\tau(\lambda,h)}{\partial h}\beta[\lambda,T(h)]dh d\lambda$$

where

E	is the detected radiance,
λ	is the wavelength
$\phi(\lambda)$	is the filter function $[\phi(\lambda)=0$ outside the interval $\lambda_1\ \lambda_2]$
$\tau(\lambda)$	is the transmissivity from height h to the satellite at height h
$\tau_S(\lambda)$	is the transmissivity from the radiating surface to the satellite,
$\varepsilon_S(\lambda)$	is the emissivity of the radiating surface,
$\beta(\lambda T)$	is the Planck function,
T	is the absolute temperature, and
T_S	is the temperature of the radiating surface.

The contribution to the total measured radiance by the first term on the right side of the equation is the measured radiance from the surface of the sea. This radiation emanates from the first few microns of the surface of the sea, and may be quite different from the usual "bucket" temperature measured by ships at sea. This difference in readings has been called the "micro-surface effect" by Warnecke et al[5].

Examining the micro-surface effect, McAlister[11] studied the physics of heat transfer at the sea surface, both in situ and in the laboratory. He determined that the radiation loss for water surface comes from the top layer by molecular conduction. McAlister used a vessel filled with water in thermal equilibrium to show that the temperature gradient in the surface layer is maintained even under vigorous stirring. The micro-surface effect is extremely stable and must be considered when combining radiance-derived temperatures with temperatures obtained by conventional means. Conventional bucket or intake temperatures are sampled well below the micro-surface.

The sea surface is not quite a black body in the 3.5 to 4.1-micron region and in the 8 to 12-micron region. Griggs and Marggraf[12] estimate an ocean surface emissivity of 0.987 in the 8 to 12-micron window. Table 1 after Bramson, Zel'manovich and Kuleshova[13], lists figures for the emissivity of liquid water as a function of zenith angle and wavelength in the 3 to 4-micron window.

Table 1.

λ [μ]	θ=0°	θ=30°	θ=60°	θ=80°
3.40	0.966	0.965	0.919	0.622
3.50	0.969	0.968	0.924	0.627
3.60	0.972	0.971	0.928	0.632
3.70	0.974	0.973	0.931	0.638
3.80	0.976	0.975	0.935	0.643
3.90	0.977	0.976	0.937	0.646
4.03	0.978	0.977	0.938	0.648
4.10	0.978	0.977	0.938	0.648

The second term of the equation represents the contribution to the total radiance originating from the atmosphere, and is commonly called "atmospheric attenuation". In the 3.5 to 4.1-micron atmospheric window, absorption is caused primarily by water vapor and carbon dioxide. Methane and nitrous oxide are the most significant of the minor constituent absorbers. Theoretical computations accounting for the absorbing effects of water vapor and carbon dioxide for a number of model atmospheres have been made by Kunde[14]. Figs. 2 and 3 compare the atmospheric attenuation effects on HRIR for various model atmospheres and for the two water-vapor windows.

Table 2 by Warnecke et al[5] summarizes the total mean correction to the measured radiometer temperature based on experience with Nimbus II. In assessing the use of radiance-derived SST values through a more precise determination of corrections, Greaves et al[8] feel that it is not possible to account for the absolute effects of atmospheric attenuation on a real-time basis. While the atmospheric absorption effects vary in both space and time, they can be treated as "slowly varying" functions of space and time. Therefore, while the atmospheric absorption may not be determinable on a given day, the SST gradients derived from satellite soundings should not be affected. Although ways to evaluate the radiative transfer equation are being investigated, it appears that the use of radiance-derived SST information should be restricted to gradient information combined with temperature values obtained by conventional shipboard means (primarily either sea water intake temperatures or bucket temperatures). The ability to take this approach is one of the fundamental strengths of the FCA analysis scheme.

TABLE 2.

Correction due to	°K
Micro-surface effect	+ 0.6
Minor constituents absorption	+ 0.5
Water vapor and CO_2 absorption	+ 2.0
Emissivity effect	+ 0.7
Total	+ 3.8 ± 2.0°C

While experience in measuring sea-surface temperature is based on the 3 to 4-micron window measurements of Nimbus II and Nimbus III, the operational SST program must rely on 10 to 12 micron window measurements from ITOS-1. These measurements should provide some benefits over measurements in the 3.5 to 4.1-micron window. Daytime thermal measurements from ITOS-1 will be less suspect of contamination by solar radiation than were the measurements from Nimbus. Second, ITOS-1 will have an albedo channel which provides a capability for cloud discrimination. Third, the correction for the deviation of the sea surface emissivity will be lower since the sea surface is closer to being a black body in the 10 to 12-micron region than it is in the 3 to 4-micron interval. Finally, the higher energy levels available in the 10 to 12-micron region should allow improved signal-to-noise ratios, and consequently better thermal resolution. The ITOS-1 scanning radiometer will have at least one disadvantage. The 10 to 12-micron window is not as "clean" a window as the window in the near infrared. The correction for atmospheric attenuation must be greater than in the case of the Nimbus readings, due to the larger and perhaps more variable water-vapor attenuation. The vagaries of water-vapor attenuation may further obscure the already difficult problem of assessing atmospheric attenuation, forcing even heavier reliance on gradient analysis. We can only conclude that while Nimbus data provide a guide to how we can best derive SST from satellite data, the details in an operational model must wait until ITOS data are routinely available.

Data handling poses a major concern in the analysis of satellite-derived sea surface temperature fields. There presently exist some conflicts between what existing data-handling facilities can provide and what is required in the analysis of sea surface temperature.

Current high-resolution satellite sensors virtually swamp data processing facilities, providing potentially far more data than can be handled by these facilities. For any data-processing system, we can define a total information handling capacity. This then becomes the limiting factor in handling satellite data. The ultimate utility of the data then depends to a large extent on how efficiently we partition the information capacity between spatial and quantity resolution. For example, by accepting coarser spatial resolution, one can gain in the temperature resolution of the sea surface temperature fields.

Unfortunately, infrared satellite sensing of sea surface temperature demands both high spatial and temperature resolution. The difficult cloud contamination problem, for example, demands high spatial resolution. The high temperature resolution requirement can best be illustrated by examining a typical sea surface temperature analysis. In Fig. 4[15], a mean monthly sea surface temperature analysis, note that the temperature gradients vary from very strong, as in the vicinity of the Kuroshio current, to very weak, as in the region of the subtropical Pacific high. In the mid-Pacific, the gradient is roughly 1°C for each degree of latitude.

If the satellite record were to provide a sea surface temperature accurate to the nearest degree centigrade for each degree of latitude, the implied gradient analysis would be seen in Fig. 5a. On the other hand, if the sea surface temperature were accurate to 0.25°C, the analysis of the gradient for the same temperature values may become as shown in Fig. 5b. Note that the gradient between the 17°C and 18°C isotherms varies by a factor of 6 from the tightest to the loosest. In terms of a typical analysis, as shown in Fig. 4, this includes most of the significant gradient information except in areas of very strong or very weak gradients. We therefore conclude that a resolution of 1°C per degree latitude is inadequate.

What sort of resolutions should we expect? The ITOS-1 instrument has a published noise equivalent temperature difference (NEΔT) of 1°C at a scene temperature of 330°K, degrading to a NEΔT of 4°C at a scene temperature of 185°K (Albert[16]). At typical sea surface temperatures, the actual value of a single observation of sea surface temperature should be measurable to within 1°C. If we assume random noise, however, and N observations of sea surface temperature, then the observed value of sea surface temperature can be expected to lie within (NEΔT)/N degrees centigrade of the true sea surface temperature. Therefore, in reducing a 2048 X 2048 matrix to a 512 X 512 subset, a temperature resolution of up to 0.25°C can be expected, assuming the digital record retains resolutions of up to 0.25°C in its temperature values. Therefore the satellite instrument has the potential of providing adequate temperature resolution for SST analysis.

There are several approaches to archiving data resolutions of 0.25°C within existing data-handling capabilities. At present, the most attractive but not necessarily the best approach is the concept of a non-linear archive. In this approach, cold temperature and very warm temperature ITOS radiometer data are processed to a coarser resolution, on the basis that higher resolution is not needed for the usually intended meteorological applications. The residual data-handling capability thus gained is then applied to better resolution in the range of sea surface temperatures.

We can conclude that the potential for accurate sea surface temperature data exists in the current ITOS satellite system. Significant problems remain, however, in translating this potential into a viable operational program.

The approach presently pursued by the Naval Weather Service uses satellite gradient data combined with routinely available ship data to prepare SST analyses. An analysis program capable of accepting both ship data and satellite data is currently in use operationally at FNWC Monterey; however, the present input is limited to ship data. Current efforts are directed toward developing satellite data inputs into the Monterey analysis.

A day's data from the ITOS-1 radiometers, after data reduction and mapping by the National Environmental Satellite Center (NESC), will consist of more than 65 million bits of information. At current transmission rates over the Navy Environmental Data Network (NEDN), these data would require more than 5 hours transmission time. This represents more than 20 percent of the entire environmental net data time, dedicated to a single product. Such transmission times are unacceptable. Therefore, satellite data handling is being treated as a two-step program, involving Navy computers at both Suitland, Maryland and Monterey, California. As the first step, the computer at Fleet Weather Facility, Suitland will be used to extract appropriate data from the ITOS-1 radiometer records. Data over land will be rejected. Remaining data will be screened using information from both the visual and infrared channel of ITOS-1 to discard obviously cloud-contaminated data. The remaining data will then be combined into a 512 X 512 array for transmission to FNWC Monterey. Final processing and blending of data into an analysis will then be performed by the Monterey computers, using the techniques previously discussed.

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Figure 1

TRACK CHART OF THE WORLD

SHOWING SELECTED TRACKS WITH DISTANCES FROM PLACE TO PLACE IN NAUTICAL MILES

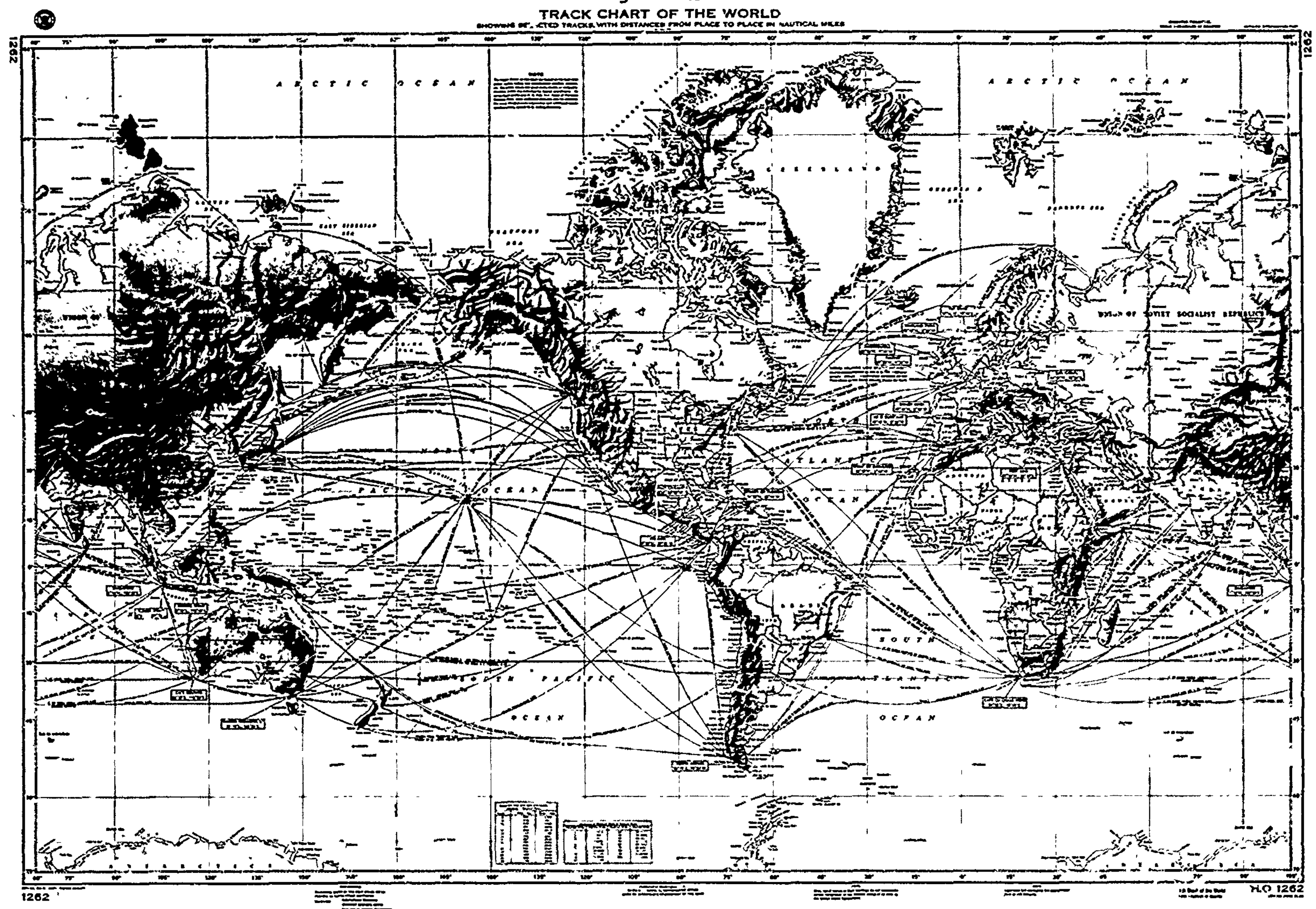


Figure 2
Theoretical surface temperature minus 3 to 4-micron HRIR equivalent blackbody temperature as a function of zenith angle for model atmospheres. A surface emissivity of unity and clear sky conditions have been assumed. (after Kunde).

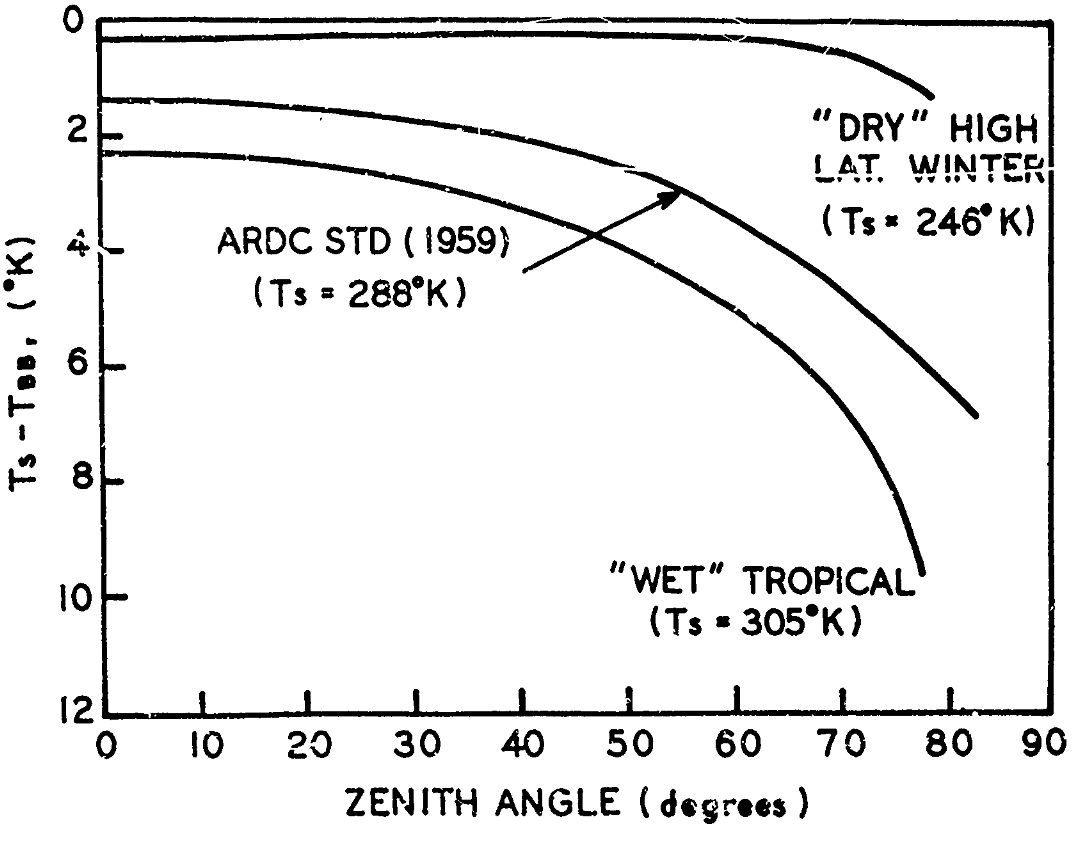


Figure 3
A comparison of the theoretical temperature difference as a function of zenith angle for the Nimbus I HRIR 4-micron window and the TIROS VII 8 to 12-micron window. The results are for clear sky conditions, the ARDC Std. (1959) Atmosphere and a surface emissivity of unity. (after Kunde).

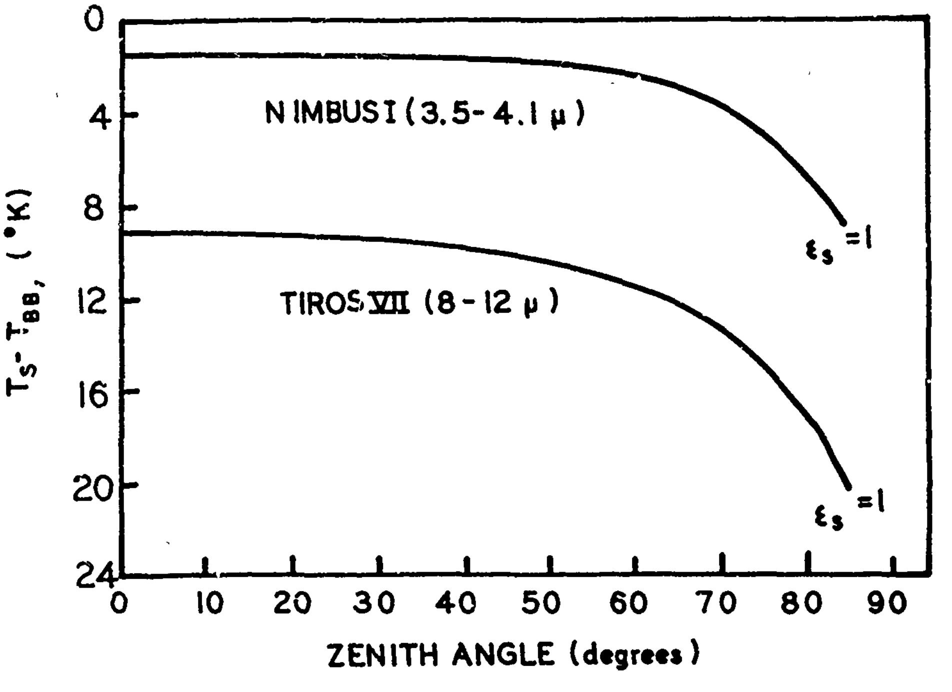


Figure 4 - Mean sea surface temperature (°F), September.

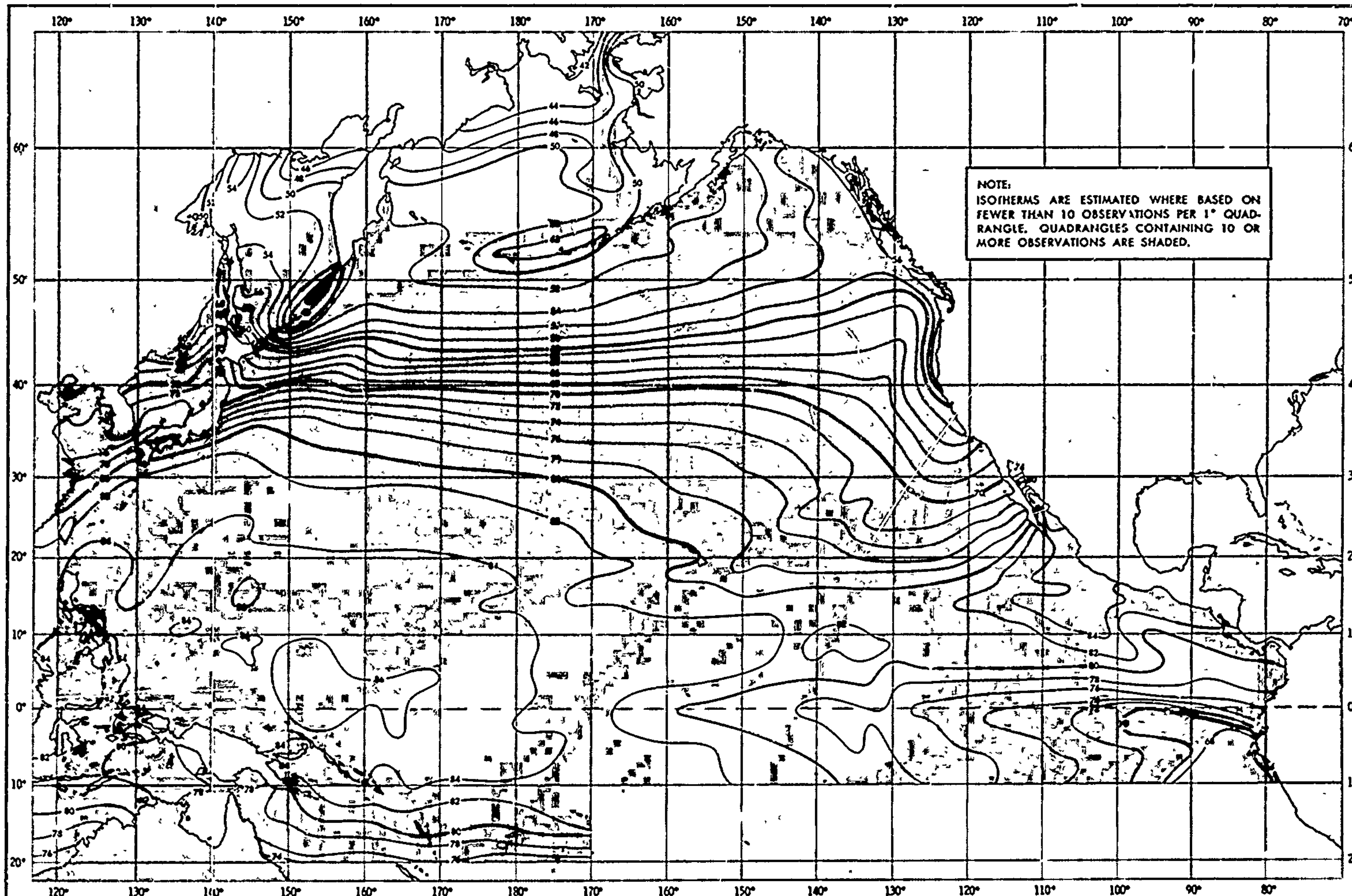
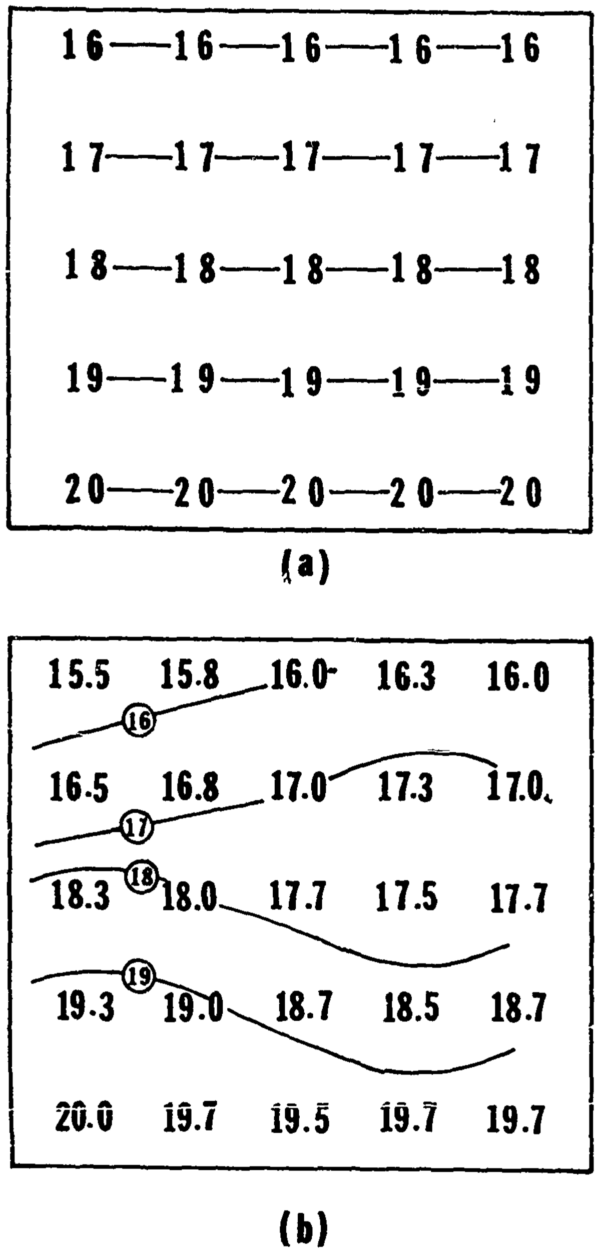
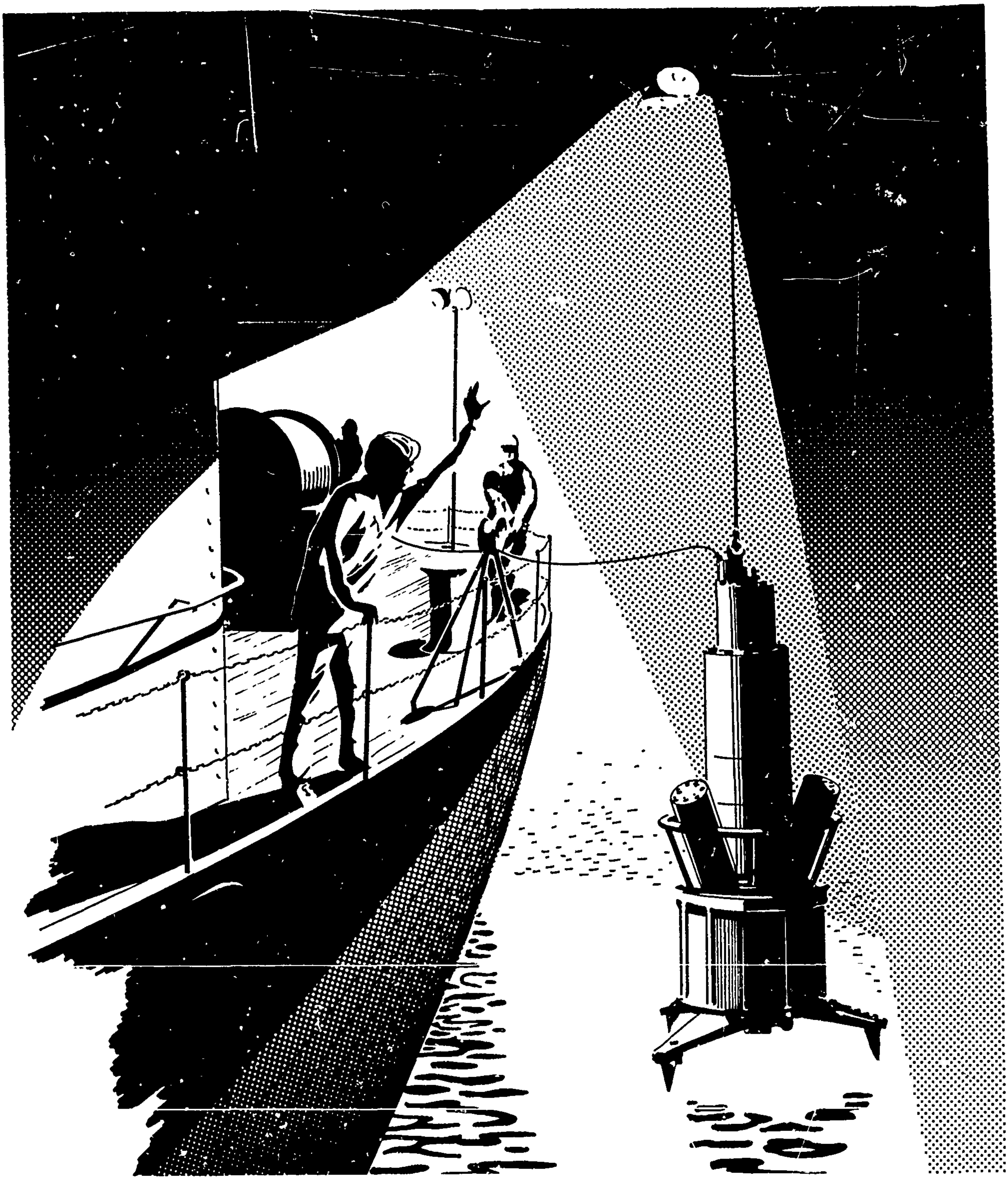


Figure 5
(a) Isotherms resulting from grid point sea surface temperature values specified to whole degrees centigrade. (b) Isotherms resulting from specifying the same temperatures as in (a) to the nearest 0.1°C.



Knowledge of Machinery for Use in the Sea



OPERATING PROBLEMS FOR MACHINERY IN THE SEA

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ABSTRACT

Many engineering problems must be solved before reliable, lightweight, high efficiency machinery components can be developed for use in the hydrosphere. This paper categorizes some of these problem areas and identifies specific goals which the designers must aim for.

Though engineering guidelines and codes for the design of machinery and machinery components for use in the ambient atmosphere exist in great abundance, there is a scarcity of such information when applied to these same components for use in the hydrosphere. Perhaps the most apparent difference between these two environments is the rapid pressure increase machinery is subjected to as it is submerged in the hydrosphere. This pressure increase is approximately one psi for every two and one-fourth feet of depth so that at 32 feet the pressure increase is already equivalent to one atmosphere, and at 3000 feet it is approximately 100 atmospheres. Though the effects of pressure variation on equipment design and performance are most dramatic, there are other more subtle variations resulting from changes in water temperature and chemistry which can greatly affect operating performance and overall machinery reliability. These variations can be a function of depth or of location in the oceans of the world.

It has been our observation that much of the equipments (machinery) being specified or selected today for use on deep-diving submersibles or bottom-type installations are none other than equipments designed for use in the air atmosphere and modified to operate successfully in the hydrosphere. All too frequently this type of a design approach results in unsatisfactory performance and reliability. We all know, however, of cases where externally mounted equipments, such as oil-compensated main propulsion motors, have performed moderately well and with some degree of reliability on small deep-diving submersibles. Unfortunately, these are too frequently the product of a "quick-fix" or a fix which does not lend itself to an extrapolation to other sizes, designs and/or operating conditions. In spite of the many claims being made for components designed and engineered for use in the hydrosphere, too many of them fail to perform as advertised. This is particularly true of rotating equipments where dynamic seal problems are so acute.

No doubt American industry can solve the engineering problems associated with design and operation of machinery for hydrospace applications; however, this will probably not come to pass unless industry can see a profit return on the large investment it may require to solve some of these problems. Probably one classic exception to this is the underwater equipments developed for and used by the off-shore oil-drilling rigs. Here the available commercial markets exist to support the machinery and equipment development costs. Unfortunately, because weight, volume and overall operating requirements are less critical than those required by the Navy, much of this excellent work is not transferable.

The Navy through various Deep Ocean Technology Programs, and I include in this the work done by and for DSSP, have done much to advance the state-of-the-art for designs of deep ocean machinery, materials, structures, etc.; but what may be more important is that through this work, problem areas have been sharply brought into focus. The clear recognition of the technological deficiencies is a prerequisite to the remedial design action which must be undertaken.

I would like to briefly touch on some of the broad general problem areas, as we have identified them, and give a few examples of requirements which must be ultimately met. Many of these problems are presently being investigated.

1. Fluids for Pressure-Compensated Machinery. A need exists for a family of fluids with:

   a. Viscosities between one cs and 30 cs
   b. Good lubricity with up to 3% sea-water content
   c. Good corrosion protection with 3% seawater
   d. High flash point
   e. Good electrical dielectric properties

2. Insulation systems for electric motors, switches, etc., which are:

   a. Compatible with petroleum base and silicone oils containing 3% seawater
   b. Adequate for sea-water-flooded systems
   c. Rated for five-year life
   d. Rated for greater than 212°F in water

3. Sealing systems for rotating shafts which:

   a. Seal oil to seawater interfaces with less than .5 cc per hour leakage
   b. Simple in design and maintenance
   c. Seal oil to oil interfaces where different viscosities are desired

4. Electronic power systems for processing and control of electrical power.

   a. Need for reliability data for oil-immersed components with cyclic pressure t rated power
   b. Need for leak-p: of filter capacitors for oil immersion
   c. Simple compensa or design
   d. Contactors - fluid-immersed with predictable long life
   e. Insulation for heat sink mounted components
   f. Fuses with long life in oil

5. Sea-water-filtering techniques which prevent clogging and fouling of compensators and other sea-water-flooded machinery components.

6. Sea-water-lubricated bearing design criteria in the low speed high force regions.

7. Machinery cooling techniques and design criteria for sea-water-immersed machinery.

8. Speed reduction devices which are:

   a. Pressure-compensated (preferably with fluids compatible with motors)
   b. Efficient (i.e., greater than 93% per 10:1 stage)

c. Quiet
d. Tolerant of sea-water leakage (3%; 100% desired)
e. Relatively lightweight
f. Need - design criteria for gears in light oils with sea-water content - traction properties of oils with sea-water content

9. Dc motors - fluid-filled need:

   a. Better design criteria for brushes, balance, cooling, magnetic compensation, insulation, etc.
   b. System of filtering carbon and other solids
   c. Design criteria for sea-water content (leakage)

10. Ac motors - oil- or sea-water-flooded need:

   a. Less expensive insulation techniques
   b. Compensating fluids (see 1); insulation systems (see 2); dynamic seals (see 3); electronic power systems (see 4); sea-water filtering (see 5); sea-water-lubricated bearings (see 6); machinery cooling techniques (see 7)

11. Motor controllers need:

   a. Reliable inexpensive inverters for ac motors
   b. Compact dc motor starter
   c. Those problems listed for electronic systems (see 4)

12. Cables and connectors

   a. Military specification connectors too large, expensive, and require excessive delivery time
   b. Molding of military specification connectors not reliable, too expensive, may not last five years

I am sure some of those presenting papers today will address themselves to many of the problem areas I have outlined. No doubt the planned Deep Ocean Technology Program will ultimately obtain many of the needed answers. Others will come from private companies who are working towards the same common goal--that of developing reliable machinery and equipments for use in the hydrosphere.

CONSTRUCTION, RATING, AND INSERVICE INSPECTION OF TEST TANKS

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ABSTRACT

Considerable guidance with respect to the construction of Test Tanks is available from the Boiler and Pressure Vessel Codes developed by the American Society of Mechanical Engineers. Recent developments in these Codes, and in the supporting activities relative to Test Tanks are discussed. Because of the importance of inservice inspection procedures, the status of the acoustic emission technique is discussed in some detail.

INTRODUCTION

A large number of Test Tanks are being used for oceanographic research. These are generally characterized by large size, high working pressure, large numbers of pressure cycles, large penetrations for machinery and personnel access, and the need for highly reliable performance. Therefore, they are critical pressure vessels at or beyond the extremes of the state-of-the-art.

This paper is intended to guide the users and purchasers of such vessels to the best presently available procedures and to acquaint them with some new techniques which have reached the stage of development where their use should be considered. We have addressed ourselves both to new construction and to the problem of evaluating existing equipment.

Most of the guidance contained in this paper is based upon developments in the design and evaluation of nuclear reactor pressure vessels, which are similarly critical vessels. We recognize that there are necessary differences between such vessels and the Test Tanks of specific interest to this conference, and that we have not attempted to reconcile all differences. Our purpose is to introduce the parties to one another, not to consumate the marriage.

CONSTRUCTION STANDARDS

We use the word construction as on all-inclusive term comprising materials, design, fabrication, examination, testing, inspection and certification. This particular set of terms follows the general practice of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, and those not experienced with the Code are sometimes confused by this specific use of the last four terms. The ASME Codes become effective when legally adopted by a State, Municipality, or Canadian Province. Such adoption establishes a basis for appointment of "Authorized Inspectors", who are employed by a State, Municipality, or Province or are regularly employed by an insurance company authorized to write boiler and pressure vessel insurance. When an action must be taken by an "Authorized Inspector" it is termed "inspection". When an action may be taken by someone other than this "third-party" individual, it is termed "examination". Testing refers to such actions as hydrostatic pressure testing. "Certification" refers to the action taken by each of the parties involved to indicate his acceptance and discharge of the several responsibilities assigned to him when he signs the appropriate Data Reports. The ASME Codes and their "third-party" inspection procédure (more formally referred to as the National Board of Boiler and Pressure Vessel Inspectors) are a complete system. Elimination of any step in the system as by following only one portion of the Code or by constructing equipment to "meet the intent" of the Code, is dangerous. It can be safely done, as demonstrated by the experience of the U. S. Coast Guard(1), if one maintains a detailed knowledge of Code activities and substitutes equivalent requirements for any Code requirements eliminated.

The preceding paragraph has been written in such detail because our apparent goal in writing this paper is to encourage those involved with the construction of Test Tanks to take maximum practical advantage of the ASME Codes. In particular, we believe that the majority of the Test Tanks in existence or planned can benefit from consideration of one or more of the following Sections of the ASME Boiler and Pressure Vessel Code:

Section III Nuclear Vessels	Since 1964 has provided comprehensive rules for construction of nuclear vessels. However, the 1971 edition which is now being prepared will cover all primary system components (vessels, piping, pumps, and valves), including both metal and concrete vessels.
Section V Nondestructive Testing	Presently being prepared for the 1971 edition and intended to combine all aspects of nondestructive testing now contained elsewhere in the Code except for acceptance standards which will be kept in the specific vessel sections.

Superior numbers in parentheses refer to similarly numbered references at the end of this paper.

Section VIII Division 2 Alternative Rules for Pressure Vessels	First published in 1968, includes materials whose properties have been enhanced by heat treatment, methods for evaluation of cyclic pressures, detailed "design by analysis" procedures to cover complex designs or conditions, elimination of a maximum pressure limitation, improved material toughness rules, and higher allowable stresses
Section X Fiberglass - reinforces plastic pressure vessels	First issued in 1969, is quite restrictive in scope and applies some interesting concepts for mass - produced hyperbaric chambers.
Section XI Inservice inspection of nuclear reactor coolant systems	First issued in 1970, Covers classification of areas subject to inspection, within defined system boundaries, fixes responsibilities, provisions for accessibility, definitions of examination techniques and procedures, personnel qualifications, frequence of inspection, records, mapping, evaluation of inspection results, disposition, and repair requirements.

If nothing else, this list should convince those involved with Test Tanks who may have decided a few years ago that the Code was of limited value to take another look.

The Code Section which by scope and intent is most applicable to Test Tanks is Division 2 of Section VIII. The best documentation of the background and documentation of Division 2 is a booklet entitled, "Guide to Alternative Rules for Pressure Vessels" which is available from ASME(2). The goal in preparing Division 2 was to permit higher allowable stresses than those which were conventionally used for pressure vessels without a decrease in safety. In practically every phase of construction the rules of Division 2 are most stringent, and the quality of a vessel meeting the requirements of Division 2 is substantially higher than that meeting only the requirements of Division 1 of Section VIII, the older rules, Division 2 was prepared by the same Code organization that prepared the Section III rules for nuclear vessels, the Special Committee to Review Code Stress Basis.

With respect to design considerations, Division 2 and Section III are intended to provide equivalent design. There are differences between the materials, fabrication, examination, and inspection rules of Division 2 and Section III, but the differences are small when compared to the differences between Division I and Division 2. It is our opinion that the rules of Division 2 are generally adequate for Test Tanks, in so far as they apply. However, in cases where periodic inspection is not practical or severe potential health hazards exist, selected and knowledgeable application of the more restrictive requirements of Section III should be considered.

In addition, we wish to call the attention of the reader to the more restrictive requirements of Section III, as opposed to all other sections of the Code, with respect to the steps required to obtain ASME authorization to construct Code vessels. At the present time, any manufacturer authorized to construct Division 1 vessels may also construct Division 2 vessels, we believe that the purchaser should take additional steps to assure that potential vendors are qualified. Such steps could well follow the Quality Assurance Program evaluation procedure contained in Section III, which is based upon the sucessful application of similar procedures by the Department of Defense.

There is one last reason why we have referred to the ASME Codes for nuclear components. The reliability of a Test Tank is no better than is the reliability of the associated equipment. Codes equivalent to the Section III rules for vessels have been prepared for piping(3), pumps, and valves(4). These rules are being incorporated in the 1971 edition of Section III, as are new rules for support of piping and equipment. Such rules should be of value to those constructing Test Tank Systems.

FAILURE PREVENTION

The most probable Test Tank failures modes are fatigue or brittle fracture. Fatigue failures may occur as a result of pressure cycling or as a result of opening and closing operation, and may result from but a few or from many millions of such operations. Brittle fracture is generally considered to occur at low temperatures and to initiate from a defect which is present from fabrication or results from prior operation. However, with the materials and thicknesses involved in some Test Tanks, even temperatures of 50-150F may be sufficiently low. With improperly treated materials, similar catastropic failures can result even at temperatures of a few hundred degrees as a result of low-energy shear fractures. Corrosion effects, particularly those which cause cracking as opposed to general attack, may accelerate failures due to fatigue or brittle fracture.

Both Division 2 and Section III of the ASME Code consider fatigue loadings in considerable detail and provide material toughness and minimum operating temperature limitations. In this respect, these documents represent significant advances over the older Codes. The remaining significant design aspect of these newer Codes is the procedure which has been termed "Design by Analysis"(5). Rather than providing simple thickness equations, one must consider the detailed stresses which result from the actual conditions of operation. Not only is such a procedure essential if fatigue conditions are to be evaluated, but the designer is free to choose his design configuration. Modern methods of stress analysis(6&7) permit effective analyses of practically any configuration. It is a basic assumption of the design by analysis procedure that such modern analytical techniques be applied.

The next major advances will probably take place as the result of an extensive cooperative program on heavy section steels developed approximately three years ago by the Pressure Vessel Research Committee. The three major facets of this multi-million dollar effort are:

1. The Heavy Section Steel Technology Program(8,9) sponsored by the Atomic Energy Commission and directed by the Oak Ridge National Laboratory. The tasks of this program include:

   a. Material Procurement, Inspection, & Control - concerned with the procurement, inspection(10) and disposition for testing of approximately one-half million pounds of 10 - 12" thick plate plus weldments.
   b. Material Characterization and Variability - concerned with a complete study of the purchased material.
   c. Transistion Temperature Investigations - concerned with size effects on the NDT transistion temperature(11) and on dynamic tear test behavior(12).
   d. Fracture Mechanics Investigations - concerned with:
      (1) Compact Tension (K_{Ic}) tests up to 12" thick(13).
      (2) Strain rate and crack arrest studies.
      (3) Gross strain measurement of fracture toughness(14).
      (4) Two and three dimensional elasti-plastic stress and strain analysis(15).
   e. Fatigue and Crack Propogation Investigations - concerned primarily with the effects of environment.
   f. Irradiation Effects.
   g. Complex Stress State - concerned with the behavior of flaws in the presence of complex stress states.
   h. Periodic Proof Testing & Warm Prestressing(16) (Complete)
   i. Simulated Service Test - includes tensile testing of 6" x 18" tensile specimens and 6" thick, 39 in. diameter vessels.

2. The Industries Funded Program on Inservice Inspection of Nuclear Reactor Pressure Vessels(17) sponsored by the Edison Electric Institute and the Tennessee Valley Authority and directed by the Southwest Research Institute. This program includes both the improvement of existing techniques and standards for nondestructive testing and the development of techniques for inservice monitoring. More will be said about the later aspect in the next section of this paper.

3. The Industrial Cooperative Program(18) sponsored by the designers of nuclear power systems and the fabricators of nuclear reactor vessels to establish statistical data on the properties of all (plates, welds, forgings, etc.) materials being used for fabrication of nuclear reactor vessels.

   This cooperative effort is now beginning to produce significant results, but will continue for several more years.

The number of material types being considered in this large cooperative program is somewhat limited, but the principles being developed will be broadly applicable, and appreciably less work will be required to investigate newer materials. Such new materials of interest to Test Tanks will probably be of higher strength than present pressure vessel materials. In an effort to determine the design techniques which are required to effectively use these higher strength but less ductile materials, the Pressure Vessel Research Committee has established a Subcommittee on Effective Utilization of Yield Strength. Preliminary results obtained in this program(19) indicate that appreciable progress is being made, but additional work over a broader scope is required. One aspect of this will be the development of improved fatigue analysis procedures, particularly with respect to the treatment of mean stress. The present Code rules require(20,21) that the worst possible effects of the mean, non-cyclic, stress be considered to be present. This prevents consideration of the beneficial effects of the mean compressive stresses which can be introduced in very thick-walled vessels by autofrettage, an effect which has been demonstrated to be significant in gun barrels, subjected to cyclic pressures(22).

Many of the advances(23) currently being made involve the application of Fracture Mechanics in the elastic range where it is now well developed and the extension of these techniques into the plastic range. Such techniques are important not only with respect to the prevention of brittle fracture, but also to the prediction of crack growth rates as a result of fatigue or corrosive attack. The development of such techniques will contribute significantly to the evaluation of cracks, or indications, found as a result of inservice inspections.

INSERVICE INSPECTION

The operational safety and reliability of pressure vessels is obviously enhanced by a periodic inservice inspection program. Modern developments with respect to inspection techniques(24) permit reasonable and extensive application of these procedures even in relatively inaccessible structures such as nuclear reactor vessels. The newly issued Section XI of the ASME Code attempts not only to take advantage of existing methods but to provide for the application of newer techniques which are not yet fully developed. Because of the great potential of one of these, acoustic emission, a separate section of this paper provides a review of the background and present status.

It is our opinion that Section XI is significant to the operation of Test Tanks not because of its specific content but because of the philosophy on which it is based. One should not just go inspect an existing vessel without specific knowledge of what he is looking for, where he should look and how often, what the condition was on the last inspection, and what he should do with the results. It is also important that the facility be planned so as to permit access for adequate inspection and that the equipment and techniques used provide for reproducability. Perhaps the most important step is to obtain a good set of initial records in the field using the same equipment as will be used for subsequent field inspections. It is not proper to assume that the last shop inspection, which is done with different people under different conditions, provides a proper baseline.

ACOUSTIC EMISSION

The acoustic emission technique holds the most promise for true "on-line" monitoring of pressure equipment, and is also of value during initial hydrostatic pressure tests. Before exploring the state-of-the-art of acoustic emission as a nondestructive monitoring tool, a brief historical review of the phenomenon would be appropriate, in view of the somewhat limited notoriety of the subject matter.

The expression 'acoustic emission' was coined by a Teledyne investigator (formerly Lessels and Associates) where the first studies of this emission were made in this country in the mid 50's.(25) Acoustic emission refers to the very low energy elastic pulses or waves that are induced in a metal when it is subjected to stress and deformation. These pulses are generated within the material in contrast to the more common ultrasonic techniques wherein acoustic energy is transmitted to the material With suitable instrumentation, to be described later in this paper, these extremely low energy acoustic emission pulses can be detected and the characteristics of the signals related to the structural integrity of the material and, hence, to a structure such as a pressure vessel comprised of such material.

The occurrence of noises from metals when they are deformed has been known for a long time. The metals tin and zinc exhibit considerable noise emission audible to the unaided ear and undoubtedly observed by the Egyptians and other ancient societies which made considerable use of these metals. Since tin was more widely used and is the most "boisterous" of the metals, the phenomenon came to be known as 'tin cry'. The exact origin of the phase is obscure. Notwithstanding this rather long history, the technical literature is quite barren of records noting this curious characteristic; and it is not until early in the Twentieth Century that technical reports documented its observance. In 1932 Becker and Orowan(26) described certain characteristics peculiar to acoustic emission from zinc which they noted merely as an oddity during investigations concerning other properties of the metal. A few other footnotes of similar observations were reported in subsequent years; however, it was not until circa 1950 that serious studies were made by Dr. Ing Josef Kaiser in Germany at the Technical Highschool at Munich. He experimented with many materials such as steel, brass, tin, zinc, lead, copper, and even glass and wood. In all of these he observed acoustic emission behavior of varying degrees of activity and energy. Late in 1954 the author and others, intrigued by a brief report of Kaiser's work(27), initiated a basic program to study this acoustic behavior in several materials. This work continued for twelve years primarily under sponsorship of the U.S. Air Force. The early experiments were devoted to fundamental studies concerned with the source of the emission,(28,29) while the last three years were directed toward practical applications.(30,31) Today there are approximately fifteen independent programs around the U.S. related to acoustic emission, both in the basic and applied research areas. The U.S. Navy has supported, and may well be continuing support, of such work.

Before proceeding to the results of studies to date, a description of the basic instrumentation system required for the detection of acoustic emission is presented. This will undoubtedly also serve to provide some insight into the nature and magnitude of this phenomenon.

The basic, single channel detection system is shown in Figure 1. Starting at the specimen, or surface of a structure as the case may be, a piezoelectric transducer is attached to the metal surface. Overall size of the transducer is of the order of one-half inch diameter and one-inch long including protective casing. Attachment is accomplished by means of rubber cements, magnetic holders, or other mechanical means to afford intimate contact with the metal. Epoxy-type cements and others which harden to form a brittle coupling are to be avoided, as they may tend to crack and thereby generate high energy noise immediately at the transducer. Transducers of many varieties, Rochelle salt, ADP and PZT-5 have been the most common types used in this work.

Coupled as closely as practical is the preamplifier, preferably battery operated to eliminate instrument noise. Gain of the preamplifier should be 10^3 (60 db), either continuously adjustable or in steps of 20 db. The preamplifier output generally passes through a band -pass filter to provide flexibility in precluding environmental noise that may exist due to operating equipment. Such noise is normally within a frequency band up to about 20k Hz and can be readily filtered out. From the filter the signal is transmitted to the amplifier which can be located at considerable distance if desired. Gain of the amplifier should be comparable to that of the preamplifier; i.e., 60 db.

Figure 1 schematically shows a typical laboratory setup for a tensile specimen. As load is applied to the specimen, acoustic pulses occurring within the metal propagate to the end where they are detected by the sensitive piezoelectric transducer. It should be clear from the amplification required in the system that the energy levels of these pulses are extremely small, far below the audible range of the unaided ear.

The instrumentation following the amplifier will vary depending on the particular objectives of the investigator. In many instances data is recorded on magnetic tape to provide a permanent record for subsequent detailed analysis. Generally, one or more electronic counters are used to monitor emission rate and total cumulative emission count, two parameters of significance which will be discussed in further detail below. Oscillograph chart recorders also find rather wide application to measure the average energy level of the emission at a given time. Some of the more recent instrumentation systems introduce considerable sophistication through the incorporation of process computers, particularly where multi-channel data acquisition is used. As many as thirty-two tranducers have been simultaneously employed in special investigations, on large pressure vessels.

The inherent characteristics of acoustic emission have been intensively studied and established over the years utilizing systems essentially as depicted in Figure 1. It would not serve any beneficial purpose to describe the various types of experiments and results in detail, but a few highlights are instructive in obtaining perspective of the current state-of-the-art.

Kaiser observed that acoustic emission becomes apparent during the upper portion of the so-called engineering elastic curve; reaches a maximum level of activity and energy as plastic yielding takes place; decreases rather drastically as local yielding set in; then, lastly rises again abruptly to a high level at which fracture occurs. Figure 2 is typical of this behavior and has been confirmed by many others as a generic response pattern. A second observation was that the frequency content--i.e., spectral curve-- of the emission is related to the specific material. This has been confirmed in a qualitative sense. For example, if one listens to the emission through the audio system (see Figure 1) the noise from tin appears to contain higher frequency components than the noise from zinc. Since the source emission signal is generally believed to be a very sharp spike, and therefore contains many frequency components, frequency, perse, has not been considered a significant or appropriate parameter.

Kaiser discovered what has since been named in his honor, the 'Kaiser Effect'. This refers to the fact that once a metal has been subjected to a given level of stress and deformation, during which considerable emission has been detected, re-stressing the material in exactly the same manner up to the previous level will not induce any emission. That is, the behavior is irreversible. Should the previous level be exceeded, the emission re-appears dramatically. This particular characteristic has found some limited application, but in the writer's opinion its intrinsic value as a research or practical tool has yet to be discerned.

In the course of his studies Kaiser theorized that the source of the emission was to be found in the shear deformation occurring at the grain boundaries within the materials. All of the metals he investigated were polycrystalline, commercial materials, relatively impure. In later studies by the writer, experiments were designed to establish the source of the phenomenon more precisely. As a part of this study, single crystals of specimens were used and found to be prolific in the production of acoustic emission. Although the role of grain boundaries was not eliminated as a source of the emission, these results clearly showed such a mechanism was not the only source, nor the major source. Currently, most investigators believe that several mechanisms, including dislocation motion, contribute to the emission response observed. No experiments to date have conclusively established the operative micromechanisms.

A general and consistent observation has been the existence of two salient types of emission: the so-called burst type and the continuous type. The burst type signal is typical of that induced in tin, zinc, and metals containing a propagating crack. It appears as a very short duration, exponentially decaying wave form of about 5 to 20 cycles. At low levels of strain and low propagating rates, these bursts occur at relatively widely spaced intervals of time. As the rates of deformation increase, the rate at which pulses occur increases as does the amplitude of the individual pulses. The occurrence of these burst signals is indicative of twinning in metals such as zinc and tin, whereas in steels and other non-twinning metals they indicate the presence of a propagating crack.

The continuous type emission is related to gross plastic deformation of the material. In this case the emission gives the appearance of high frequency background noise, rather than discrete burst signals. As plastic deformation progresses, the amplitude level of this continuous emission increases significantly. For relatively brittle materials the emission rises rapidly to a peak normally just prior to fracture. In ductile materials a peak will be reached followed by a rather gradual decrease in amplitude. Again, just prior to failure, the amplitude will increase noticeably and rapidly.

The above two characteristics, along with test sample correlation, are the most widely used in assessment of structural integrity during loading of a structure, as in hydrostatic testing.

The sharp and rapidly decaying burst pulses are of particular interest and one of the most valuable properties of the emission in that their occurrence at a defect provides a means of locating the defect or crack in the structure. By employing a number of the piezoelectric transducers over the surface of a structure, the time delay of the arrival of each burst at each of the several transducers can be measured. With the assistance of the computer, these time differences can be translated into a position on the structure from which the signals originate; hence, physical location of the defect producing the emission is established. Accuracy of this technique can be with a radius of uncertainty in the order of one to two feet, depending on the size of the vessel and the number and spacing of transducers.

The practical application of the acoustic emission technique has been rather tedious and somewhat slow in view of modern standards; nevertheless, some significant advances have been made. To date the application of acoustic emission has been almost exclusively applied to pressure vessel testing; i.e., the hydrostatic test, In such tests a minimum of environmental noise is encountered, greatly simplifying procedures and techniques. In the course of several laboratory investigations on small vessels, the author was able to demonstrate the ability to preclude sudden, catastrophic failure by monitoring the emission response. Several vessels contained artificial defects and their presence could also be detected. Figure 3 is a sample of the emission data obtained on two of these small vessels. In the upper figure the acoustic emission from a defect-free cylinder is shown along with the loading pressure. The two small peaks before the general rise indicate the occurrence of local plastic deformation someplace on the vessel. The rapid rise to the peak is seen to begin as the nominal stress level reaches the yield strength of the material. A gradual decrease in emission follows, which is believed to be due to the gradual development of plastic deformation over a local region. This anomaly results in a reduced volume of material undergoing plastic deformation, thereby reducing the total energy of the emission. Just prior to rupture, the emission increases again to a relatively high level.

In the lower figure the data is shown for a vessel identical to that producing the upper data with the exception of a small artifical defect placed in the surface of the vessel. The vessel was not taken to failure in this particular test, but later was ruptured at a pressure of almost 6000 psi, very slightly under that for the upper vessel.

It is immediately apparent that high energy acoustic emission occurred at a fraction of the pressure of the defect-free vessel due to plastic deformation around the defect discontinuity. The defect was not of sufficient size to seriously effect the integrity of the vessel; nevertheless, it is clear that it influenced the emission response considerably. Other types of defects in subsequent experiments exhibited similar behavior, indicating a high degree of reliability in the method.

Relatively recent field tests by other investigators have shown the efficacy of the method on spherical vessels up to forty feet in diameter. Defects were successfully located on the structures, although none of the vessels was in danger of imminent failure. A number of successful tests have been conducted on a variety of vessel sizes establishing the acoustic emission method as a valuable and practical reality. Of course the method is not foolproof. Personnel must be well experienced with emission behavior at least for the specific metal under survey. Laboratory tests on samples must completely categorize the emission for both crack propagation and plastic deformation. This laboratory data is of vital importance in the diagnostic analysis and establishment of criteria against which structural integrity is to be assessed.

At the present state-of-the-art it can be stated with reasonable confidence that acoustic emission can be successfully employed to preclude catastrophic failure of pressure vessels and to determine the location of defects on the structure during hydrostatic testing.

It is anticipated that, in the course of time, experience with this tool will result in considerable economic benefits to manufacturers and users of vessels by greatly reducing the extensive surveying required by ultrasonic and radiographic methods. The dynamic characterestics of the emission permit a complete survey of a structure with a limited utilization of fixed transducers at preselected locations. The phenomenon is unique in that the defect, perse, is the source of the information and this in turn is transmitted in such a fashion that every suspect area need not be specifically inspected as in the more common nondestructive methods.

In operation, inspection or surveillance presents a much more complex situation. In this instance general background noise from operating equipment, pumps, valves, diffusers, control rods, etc., as well as flow-induced noise and cavitation, present many difficulties in isolating and detecting the acoustic emission. At the present time, none of the available instrumentation systems is capable of adequately detecting the acoustic emission on complex operating units. Noise surveys have been conducted on operating reactors and have indicated a rather wide spectrum of noise. Nevertheless, tentative results show that band-pass filtering in the range of one mega Hertz is effective in greatly eliminating environmental noise while passing a satisfactory emission signal. The problem will undoubtedly be solved. Current progress suggests that positive results will be attained within a year. It should be noted, however, that noise surveys will probably be required for dissimilar installations and filtering techniques tailored to each specific application. Considerable effort is currently being directed toward the solution of these problems and the actual development of an inservice surveillance emission system for nuclear reactors.

The progress to date has been most encouraging; nevertheless, aside from the environmental noise noted above, there are other areas requiring developmental and research effort. Long-term performance of the piezoelectric transducers when subjected to continuous high temperature and radiation has not been adequately established. On-site calibration methods need be developed to assure optimum efficiency of the in-service detection system. One of the most important elements required will be the determination of dependable criteria against which critical operating decisions can be made.

A subsidiary element regarding the decisional response criteria is the need for further research to establish correlations between the emission behavior and the structural severity of the defect. At the present state-of-the-art the emission provides information relative to imminence of failure and the presence of a propagating crack, but does not provide knowledge of the severity of the defect at a given point in time; for example, crack length, surface area, depth, etc. These are vital pieces of data for in-service inspection and although some efforts are underway to develop this aspect, the limited activity being supported is far from adequate to provide the necessary answers in the next few years.

In summary, it has been demonstrated that at the current stage of development the acoustic emission technique is a valuable tool for certain limited, but important, applications. The technique holds considerable promise for pressure vessel technology, particularly in-service inspection. The technique is unique; no other known method offers the scope of potential advantages possible with this method from both technical and economic considerations.

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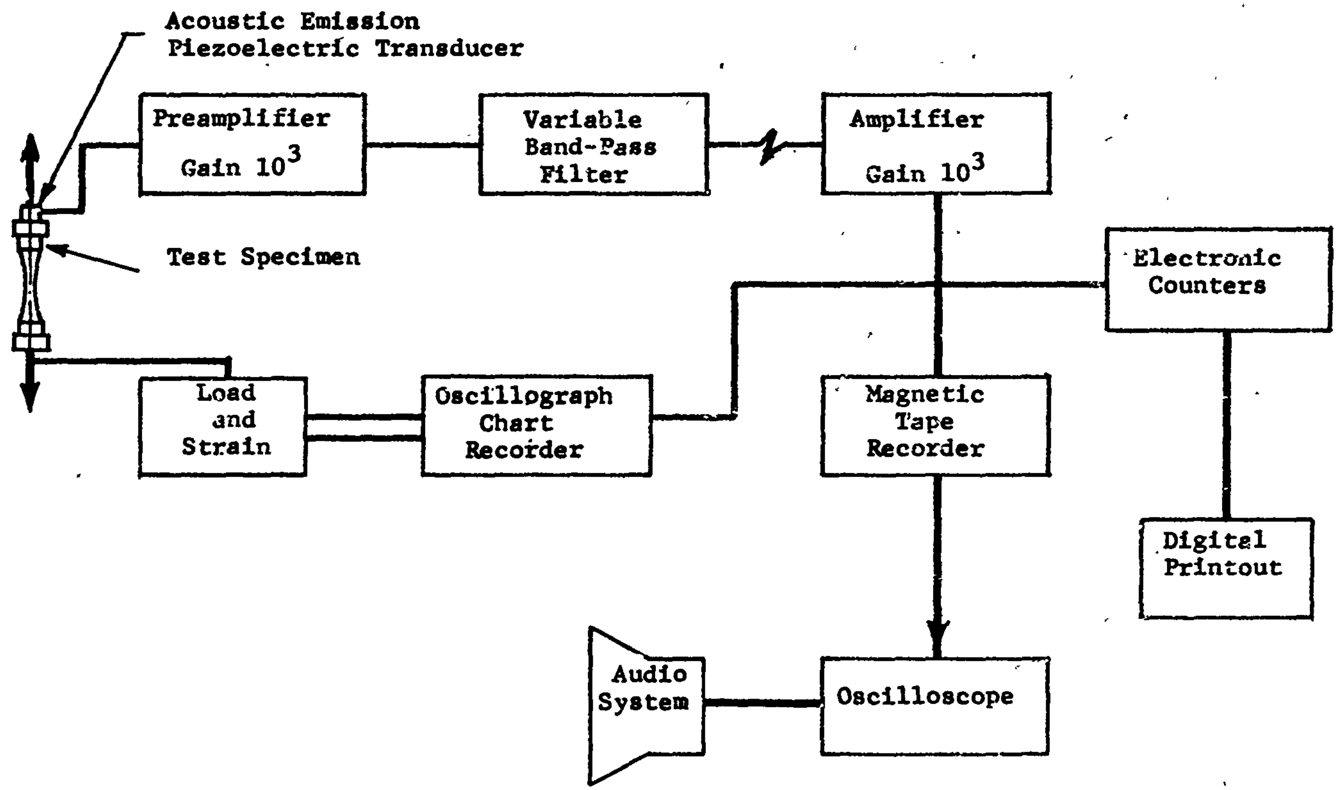


FIGURE 1. BASIC ACOUSTIC EMISSION DETECTION AND RECORDING SYSTEM

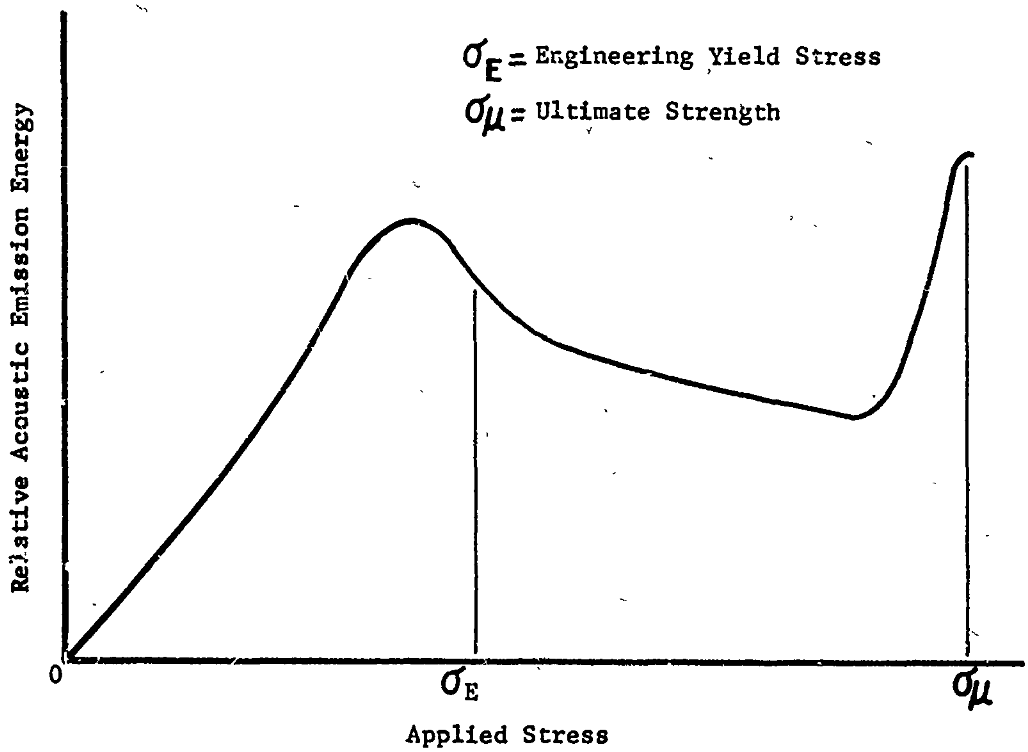
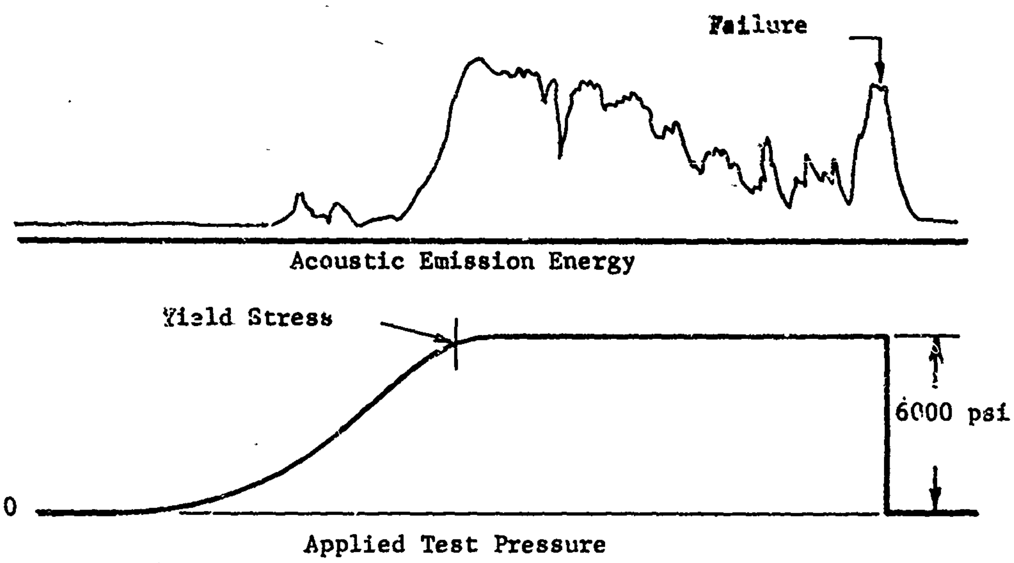
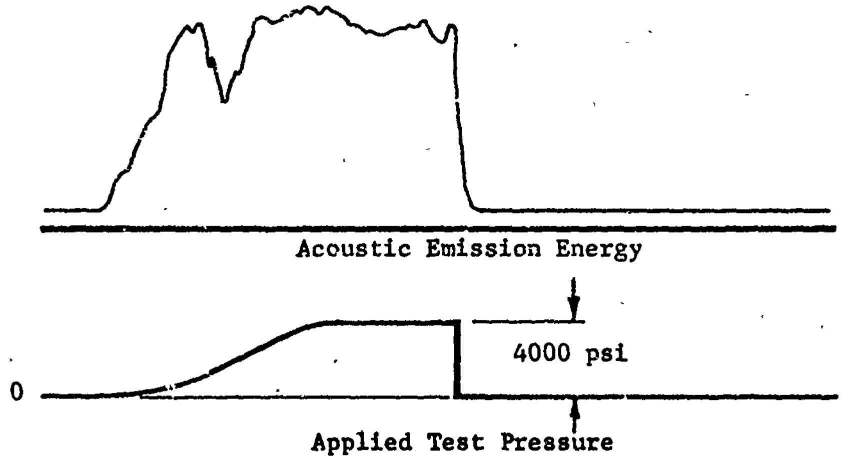


FIGURE 2. TYPICAL RESPONSE OF ACOUSTIC EMISSION ENERGY VS. APPLIED STRESS



(a) Emission Vs. Test Pressure for Defect-Free Vessel



(b) Emission Vs. Test Pressure for Vessel Containing Small Artificial Defect

FIGURE 3. ACOUSTIC EMISSION FROM VESSELS UNDERGOING HYDROSTATIC TESTS

MANIPULATOR / DEEP OCEAN TOOL WORK SYSTEM

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ABSTRACT

As man ventures more and more into undersea exploration he finds himself limited because he is outside his natural environment. Thus, he must seek help elsewhere. He uses a submersible for transportation and protection from the underseas environment and then turns to a manipulator as an extension of his own arms to do useful work. Protected inside the pressure hull of a submersible and viewing the surroundings through a view port or a closed circuit TV-camera system, he can control the manipulator so that it will accomplish useful work, such as, retrieving scientific sensors, implanting instrumentation, releasing entrapped submersibles, recovering or helping to recover lost objects, servicing habitats, or performing any other useful task beneficial to man.

A manipulator is generally designed for specific vehicle mission requirements that dictate lift capability, reach capability, number of joints, type of control, etc. However, even though a manipulator is designed to a specific set of requirements to perform a given mission, it can perform many other useful tasks.

INTRODUCTION

In ocean research manipulators are used as an extension of man's hands; specifically, manipulators are a deep ocean tool work system that is controlled by man.

What manipulators can do, what tasks some have done lately, what types we build at Westinghouse Ocean Research and Engineering Center, and how manipulators are useful for both military (mainly naval) and industrial applications will be discussed. Manipulators usually form part of a submersible work and recovery system, but we will consider them as an individual recovery tool.

Manipulators first came into heavy use in the Nuclear Industry because manipulators were the only practical method for handling radioactive materials. Now, as man broadens his exploration of the oceans, he finds himself handicapped by his lack of ability to work in the deep ocean environment, so he turns to the manipulator to extend the abilities of his own arms for useful work. In ocean research manipulators are used for scientific research, commercial operations, or military operations.

MANIPULATOR VERSATILITY

Manipulators are used to extend and augment man's capabilities in those tasks that require human judgement and control. Man's sensory assets and his complex manipulating ability guide the machine. However, the work and power output of the machine is not limited by man's capabilities. Moreover, environments that are normally hostile to a human do not affect the machine. This makes a manipulator ideal for deep ocean work. Man can sit inside the protection of the pressure hull of a submersible and guide the manipulator by means of a control device to perform useful tasks. Motions which are impossible for a human can be accomplished by a manipulator. For instan.., a manipulator may be required to continuously rotate parts such as unscrewing a nut or bolt. The wrist joint or another joint can be designed to rotate continuously on command, accomplishing this requirement.

Some missions may require the use of two manipulators where others may require only one. The following are examples of tasks that could be made easier and less time consuming with two manipulators: (1) placing cables around objects to be salvaged, (2) actuating valve handwheels, (3) holding material with one manipulator while wielding a cutting torch with the other. However, with two manipulators the submersible suffers a weight and power penalty; therefore, two should only be used where one is inadequate for the mission. If two manipulators are used they should be powered and controlled by two separate systems so that a failure in one would not affect the other.

The types of task a manipulator can perform on an underwater mission are:

Salvage
- Detach cables restraining objects to be salvaged
- Clear debris away from objects to be salvaged
- Prepare object for lifting by attaching cables
- Position objects for salvage
- Separate large objects
- Excavate bottom sediment

Undersea Rescue
- Aid in freeing entrapped submersibles
- Aid in mating of rescue submersible to submarine

Service Habitats
- Aid in heavy work operations
- Aid in replenishment of supplies
- Aid in placement and recovery of habitats

Offshore Oil/Gas Production Facilities Task
- Assist during drill string landing
- Prepare drill sites by removing debris
- Replace blowout preventer rams
- Make pipe connections
- Replace and patch pipes
- Recover objects dropped from drill platform
- Inspect oil lines using hand held acoustical devices
- Remove marine growth

Others
- Place and retrieve acoustic markers
- Place explosive devices
- Clear and remove debris
- Collect marine samples
- Position transponders
- Remove and replace defective equipment
- Take bottom core samples
- Collect mineral laden nodules

To perform these tasks a manipulator must have the capability of changing its terminal device. The term "terminal device" is used to mean either a gripping hand or a tool that can be attached to the end of the manipulator. Changing terminal devices rather than holding and actuating a tool by means of a gripping hand is better since it allows the tool to be mechanically coupled to a motor or actuator in the wrist of the manipulator. This method avoids the necessity of either using self-powered tools or having cumbersome electrical or hydraulic connectors attached to the tool. For a manipulator to be really an efficient and flexible deep ocean work tool system it must have the capability of changing its terminal device on the bottom rather than on the surface. This eliminates surfacing every time a different terminal device is required to perform part of the mission. Some manipulators such as the one built for the Deep Submergence Rescue Vehicle, have a multipurpose terminal device so that it can accomplish its primary mission without exchanging tools. Some of the tools that a manipulator should be capable of using are:

- Gripping Devices
- Impact Wrenches
- Stud Guns
- Cable Cutters
- Drill Chucks
- Grinding Wheels
- Wire Brush
- Water Jet

RECENT USES OF MANIPULATORS

In the past year manipulators have been involved in three important undersea missions. The missions were: (1) The salvage of the submersible ALVIN, (2) the salvage of a tug named EMERALD STRAIGHTS, and (3) the freeing of the submersible DEEP QUEST from an underwater entanglement. Two manipulators were used in the first two missions and one was used in the third.

The ALVIN was salvaged from a depth of 5052 feet off the coast of Massachusetts. In this case two manipulators, which were mounted to the submersible ALUMINANT, played a very important role. The manipulators first tore away portions of the ALVIN's fiberglass conning tower, thus giving a clear access to the open pressure sphere hatch. The manipulators then inserted and tripped a toggle bar in this open hatch. The toggle bar had a line attached with a snap hook fastened to the free end. After the toggle bar had been tripped, one of the manipulators attached the snap hook to a lift line and the ALVIN was then hoisted to the surface.

In the second mission involving two manipulators the submersible PISCES I salvaged the EMERALD STRAIGHTS, a 95 ton tug, from 670 feet of water off the coast of Vancouver. The first task for the manipulators was to cut the two bow anchor chains at the anchor windlass so that the chains and anchors could slide clear of the hawse pipes, permitting toggle bars to be lowered from the surface and guided into the hawse pipes with the manipulators. The chains were cut by a hydraulic cutter fixed to one of the manipulators just for this operation. The starboard chain was successfully severed by the cutter; however, the anchor hung up in the mud and did not clear the hawse pipe. The manipulators were then used to rig a chain around the anchor fluke so that it could be pulled clear from the surface. The port anchor chain was severed and fell clear of the hawse pipe as originally anticipated. Once the hawse pipes were cleared of the anchor chains, the next step was for the manipulators to install the toggle bars. This operation also had problems. The port hawse pipe was slightly curved, which caused the toggle bar being installed to jam. Here brute force proved to be the solution. A 65 pound weight was bolted to the PISCES I principal manipulator and the pilot started pounding the toggle bar. Finally, the pounding was successful but consumed 10 hours. Now, using two lift lines that were attached to the bow of the tug, the bow was lifted 10 feet. The final step for the manipulators was to pass a wire rope sling from the forward end of the tug to the stern quarter. Timber, which would splinter when actual lift began, was used as a spreader. The manipulators guided the sling and cleared it from fenders and other obstructives as it passed toward the stern. Once the sling was positioned, the tug was raised.

The mission to free the DEEP QUEST took place in 432 feet of water off the coast of San Diego. One manipulator was involved in this mission. The DEEP QUEST had both aft propellers entangled in a plastic rope that was attached to a scoop-like recovery module used to retrieve heavy test samples from the ocean floor. The submersible NEKTON used its mechanical arm to snip this plastic rope thus freeing the DEEP QUEST.

There have been many other applications, too numerous to mention, where manipulators have been used in undersea missions, but the three missions given are excellent examples of the usefulness of manipulators.

THE NR-1 MANIPULATOR

A manipulator was built for the Navy by Westinghouse for use in the NR-1 research submarine. This manipulator is considered a heavy duty type since it can lift 500 lb (air weight) vertically or 250 lb (air weight) horizontally. The manipulator itself weighs approximately 700 lb in air and 580 lb in water. It has six degrees of freedom or motions and a reach of 90 inches. The six motions are:

- Shoulder Rotate
- Shoulder Pivot
- Elbow Pivot
- Wrist Pivot
- Wrist Rotate
- Wrist Extend

The range of motion for each joint and arm lengths are shown in Figure 1.

The manipulator is mounted to a movable turret within the forward keel section of the NR-1 submarine, as shown in Figure 2. Since the turret is movable the manipulator arm gains another degree of freedom or motion. The arm is stowed in the keel as shown in Figure 3. The method for accomplishing this stow position is to first stow the arm in the configuration shown and then retract the turret-arm assembly, which is on movable rails, into the keel section. Once the assembly is retracted the keel door closes, thus offering protection to the manipulator as well as minimizing drag.

The manipulator is hydraulically powered but controlled by electrohydraulic servo-valves. The control unit is shown in Figure 4. The pendant, sitting on top of the box, is removable from the box for hand held operations and is connected to the box by two retractable electrical cables. The pendant contains the switches for controlling the joints and being portable, permits the operator to place it beside him at the viewport. Joint speeds and jaw grip force are adjustable.

The manipulator has a pair of parallel jaws as a terminal device, which is adequate for its mission requirements of retrieving objects off the ocean floor. It could, however, be fitted with a pair of cutting jaws if cable cutting is desired. At present these are the only options available for the terminal device; however, the jaws could be used to hold self-powered tools or tools with separate power supply if other objectives were required.

For safety reasons all manipulators must be jettisonable so that, if by chance the manipulator becomes entangled while working on the bottom, the vehicle can separate from it and return the crew safely to the surface. The jettison system is not a part of the arm assembly but is built into the turret on the vehicle.

This manipulator is designed such that the ambient pressure has no effect on its operation; therefore, it can operate at any depth.

An NR-1 type manipulator is presently being built for use on the Westinghouse DEEPSTAR 20,000.

THE DSRV MANIPULATOR

The second manipulator is more sophisticated than an NR-1 type and was designed and built by Westinghouse under a subcontract with Lockheed Missile and Space Division for use in the Deep Submergence Rescue Vehicle, shortened to DSRV. This arm has the capability of exerting 50 lbs of force at its terminal device in any direction. It has a reach capability of 92 inches from the shoulder pivot and 123 inches overall and weighs approximately 550 lb in air and 350 lb in water. The arm has six degrees of freedom or motion:

- Shoulder Rotate
- Shoulder Pivot
- Elbow Pivot
- Wrist Vertical Pivot
- Wrist Horizontal Pivot
- Wrist Rotate

The range of motion for each joint and arm lengths are shown in Figure 5. The manipulator's mounting position on the vehicle is shown on Figure 6. For minimum vehicle drag and protection from accidental damage the manipulator stows inside the fairing of the vehicle. Figure 7 shows the manipulator in stow position while undergoing acceptance testing at Westinghouse. The semicircular portion of the fixture simulates the lower portion of the submersible including structure. Since the stowage area is small and out of the field of view of the operator the manipulator is automatically stowed and unstowed by a computer program. An added requirement is that stowing and unstowing be accomplished with the submersible sitting on the submarine, which means that during the stow-unstow operation the manipulator arm must at all times stay above the bottom of the mating skirt. This computer program adds an additional automatic mode to the manipulator system which provides coordinated motion of the manipulator joints to extend the terminal device along the center line of the wrist element. This motion is analogous to the extension and grasping motion of the human arm and requires only a single command. This motion is referred to as True Arm Extend and is diagramed in Figure 8. The manipulator is hydraulically powered but controlled by electrohydraulic servo-valves. Manual control of the rate of rotation of each joint is used. The vertical joints and stow actuator have feedback potentiometers mounted to them for the automatic programs. The manipulator's Control Input Device is designed to rest on the operator's lap while he is seated, viewing the motions of the manipulator thru a vehicle viewport or by a closed circuit TV system. The control unit is connected to an electronics box by a ten foot umbilical cable, which in turn has a connection to the manipulator thru a penetration in the pressure hull. The electronics box houses the analogue computer circuitry for automatic stow-unstow operation as well as true arm extend. A joystick, Figure 9, located on the Control Input Device provides the operator the selection and rates of the individual joints. The joystick has three axis of rotation. It can be displaced fore and aft, port and starboard, and rotated. These deflections will result in various manipulator actions, depending upon the deflection of a thumb-operated, five position toggle switch located on top of the joystick. Table 1 is a tabulation of manipulator responses with respect to joystick and thumb switch displacement. An added feature of this joystick control is the capability of coupling two or more motions at once. An example would be a case where the thumb switch is depressed to the left with a stick position of forward, to port, and rotated. This configuration would result in simultaneous motion from the shoulder vertical, shoulder horizontal and wrist roll joints.

The mechanics of performing the stow-unstow operation is relatively easy since the computer does the majority of the work. The stowing of the manipulator is accomplished in four steps. First, place the mode select switch into the prestow position. Second, maneuver all joints manually until they are in their prestow position. There is a light indication for each joint when it is properly positioned. Third, place the mode select into the stow-unstow mode and fourth, place the stow-unstow command switch into the stow position. As soon as the stow command is given the manipulator starts to stow. Once the manipulator has stowed and locked, which takes approximately 2 minutes 50 seconds, a light on the Control Input Device lights to indicate a successful stow operation. With the manipulator stowed and locked both the hydraulic and electrical power to the manipulator can be turned off. The unstow operation is accomplished by two simple steps after the power has been restored to the manipulator. First, place the mode select switch into the stow-unstow position and, second, give the unstow command by placing the stow-unstow command switch into the unstow position. With the unstow command given the locks retract and the manipulator unstows. Here again a light on the Control Input Device lights when the manipulator has successfully unstowed. The manipulator position at the end of the unstow program is the same as prestow position before stowing. The operator can then place the mode select switch into manual position and begin operating the manipulator.

The functions of this manipulator system during the rescue of man from a distressed submarine are simple yet demanding. In order to effect a successful rescue, the mission must be performed in the shortest possible elapsed time. The manipulator must sweep, shovel, or otherwise clear debris from the hatch of the crippled submarine. It must also grasp, cut, and remove the messenger buoy cable which may be across the escape hatch or deployed. The final function is for the manipulator to reach under the vehicle's skirt, grab the hook on the haul down winch and attach it to the bail on the submarine's escape hatch. To accomplish these tasks the manipulator is fitted with one multipurpose terminal device. This terminal device, attached to the manipulator as shown in Figure 10, has the capability of grasping objects with a single dimension of 4 inches in size, scrubbing a surface with a high speed wire brush, flushing a surface with a jet of water generated by a propeller located inside the housing of the wire brush, and cutting a wire rope cable 5/8 in. in diameter in less than 2 seconds. When using a multipurpose terminal device, a weight penalty is paid, but, because of the time element during a rescue mission, the penalty is necessary. The terminal device can be disconnected from the manipulator by a single command which physically ejects it from the rest of the manipulator. This feature is included mainly for safety reasons in case the terminal device becomes entangled while working on the ocean floor, but could be broadened to add a tool interchangeability capability to the manipulator.

The manipulator has a built-in jettison capability in the base assembly and can be jettisoned from the vehicle in emergencies.

This manipulator can not be operated independent of ambient pressure because the secondary jettison system is limited to operation in ambient pressures not exceeding 4500 psi. All other manipulator components will operate independent of ambient pressure.

CONCLUSIONS

As seen by the examples in the section entitled "Recent Uses of Manipulators," manipulator systems have played an important role in increasing man's capability to do useful work in the deep ocean environment. One can also see that more development is needed in the field of manipulators as a deep ocean tool work system to make underwater missions, such as salvage, more efficient and less time consuming. The method to advance the manipulator system state of the art is for the Navy as well as industry to progress from manipulators like the NR-1 and DSRV and to continue research and development in the areas of underwater tool interchangeability, control systems, and other areas that will increase the manipulator's capability to a point where it can perform better than the human arm with tool in hand and yet have a human arm's dexterity.

This means we need to give the operator the sense of feel of the manipulator arm, that is, the operator must feel that the manipulator is a part of his arm.

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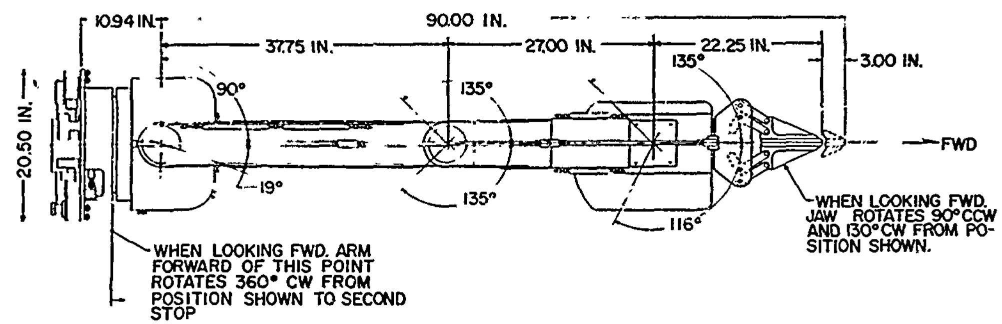
TABLE 1. MANIPULATOR RESPONSES TO OPERATOR CONTROL

STICK DEFLECTION	THUMB SWITCH POSITIONS				
	OFF (Center)	SHOULDER (Left)	WRIST (Up)	ELBOW (Right)	T. A. E. (Down)
FORE-AFT	No Action	SHOULDER Vertical	WRIST Vertical	ELBOW Vertical	SHOULDER vertical with ELBOW and WRIST vertical following according to T. A. E.
PORT-STBD	No Action	WRIST Roll	WRIST Roll	WRIST Roll	WRIST Roll
ROTATE	No Action	SHOULDER Horizontal	WRIST Horizontal	SHOULDER Horizontal	SHOULDER Horizontal



PLAN VIEW OF ARM

Figure 1. NR-1 Manipulator Arm Lengths and Joint Motions

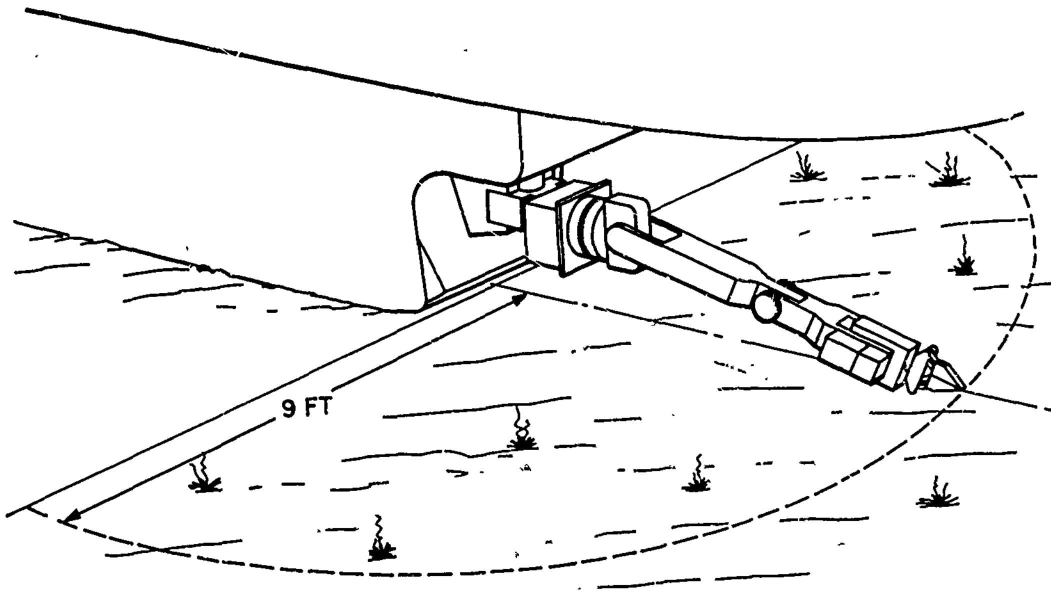


Figure 2. Manipulator Mounted to NR-1 Vehicle

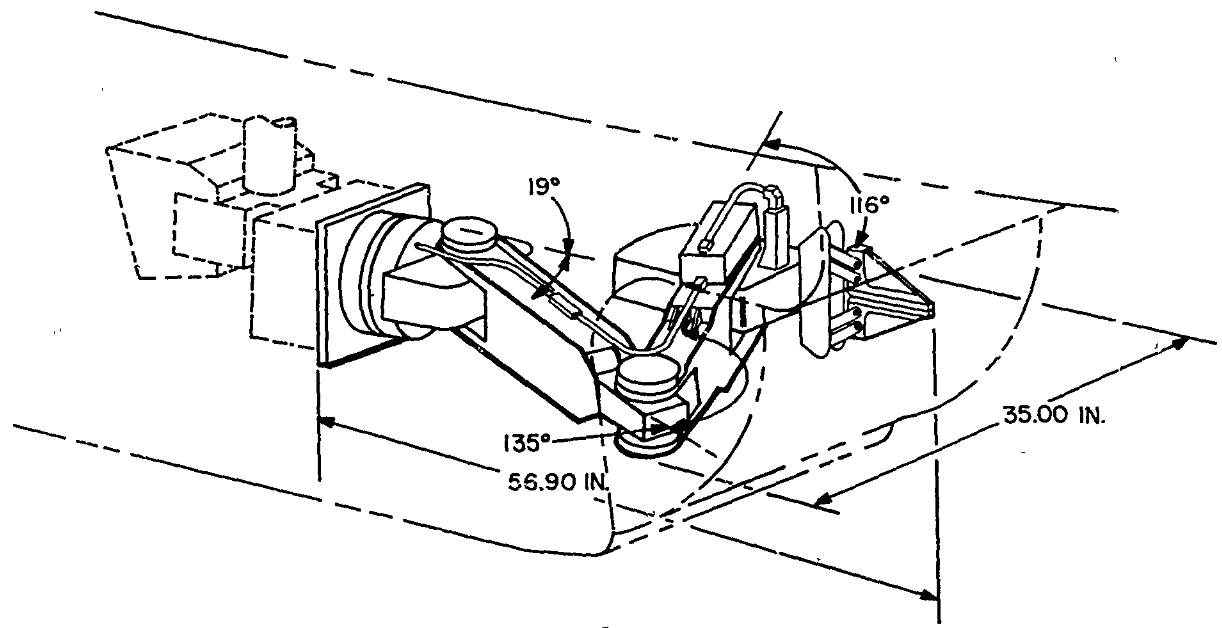


Figure 3. NR-1 Arm Stowed in Vehicle Keel

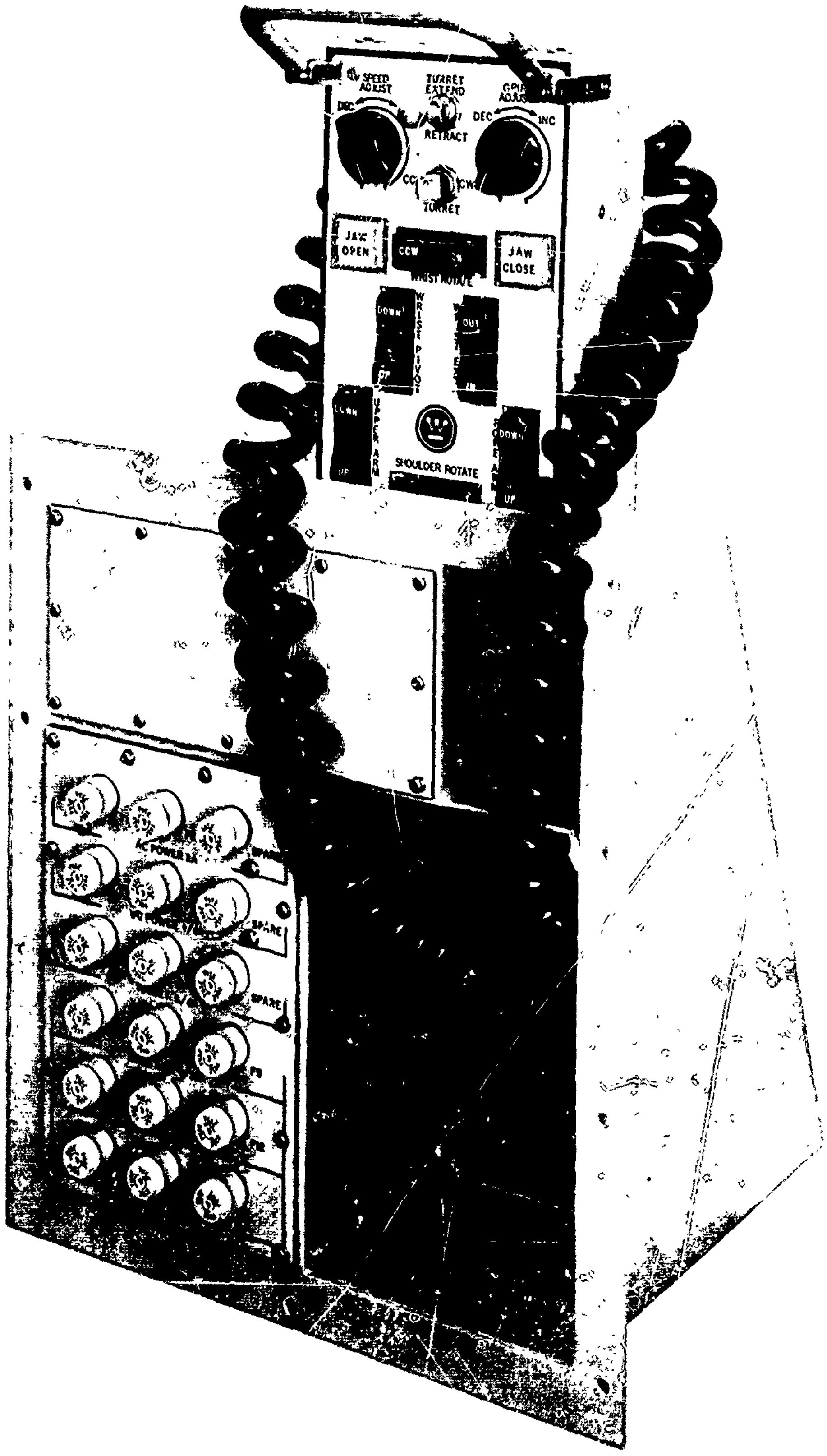


Figure 4. NR-1 Manipulator Control Unit

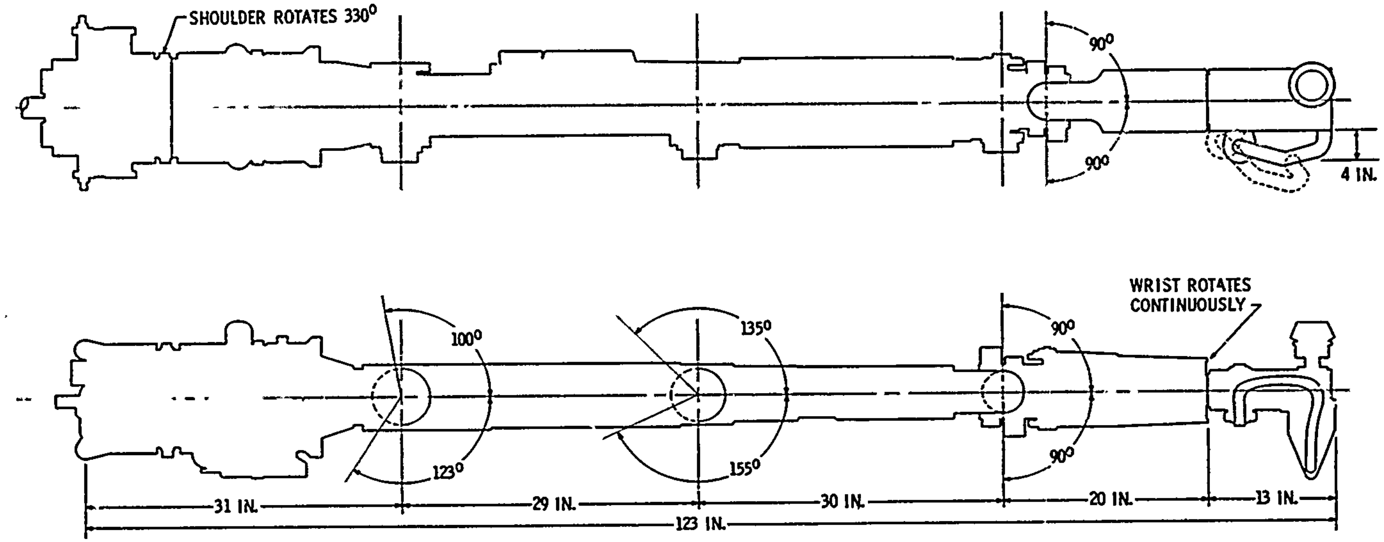


Figure 5. DSRV Manipulator Arm Lengths and Joint Motion

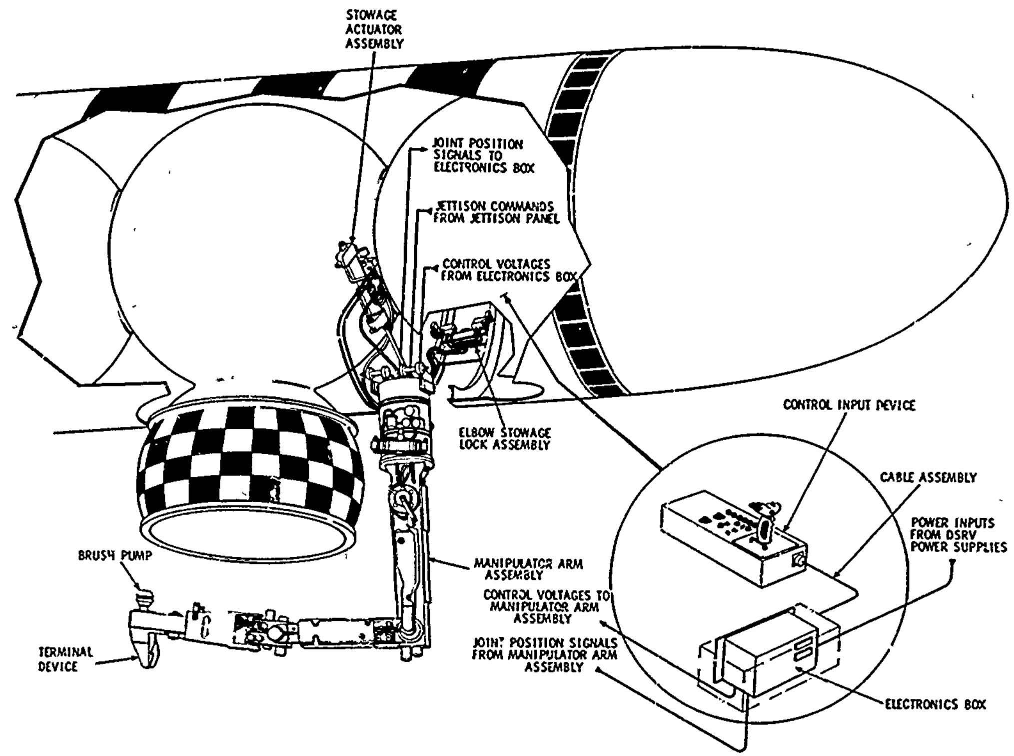


Figure 6. DSRV Manipulator Mounted To Vehicle

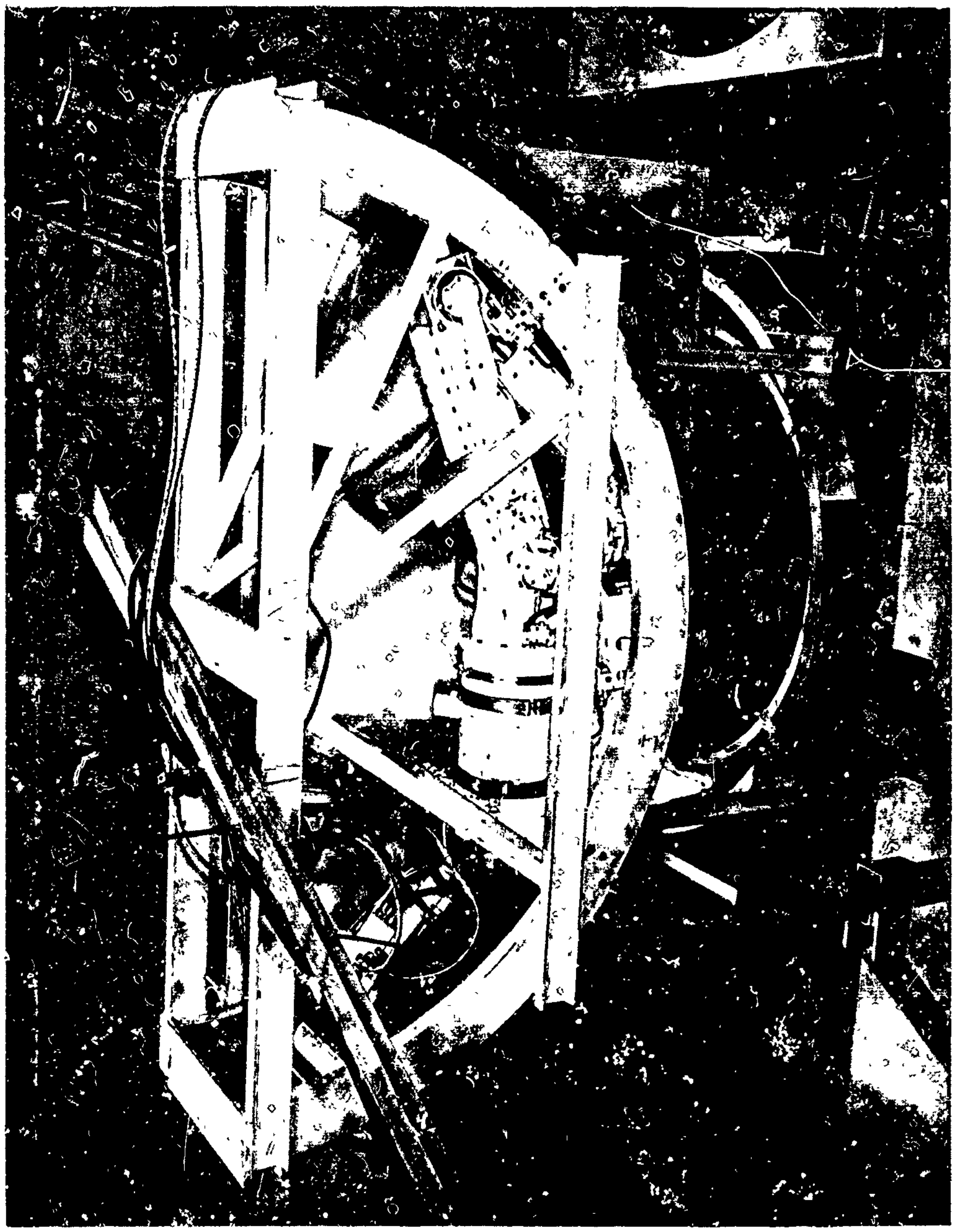


Figure 7. DSRV Manipulator in Stow Position

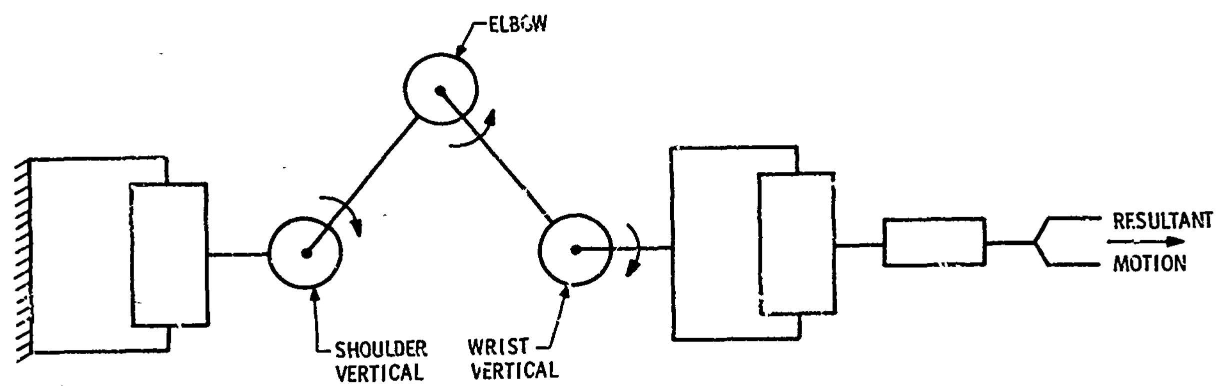


Figure 8. Coupling of Motion to Provide "True Arm Extend" Motion

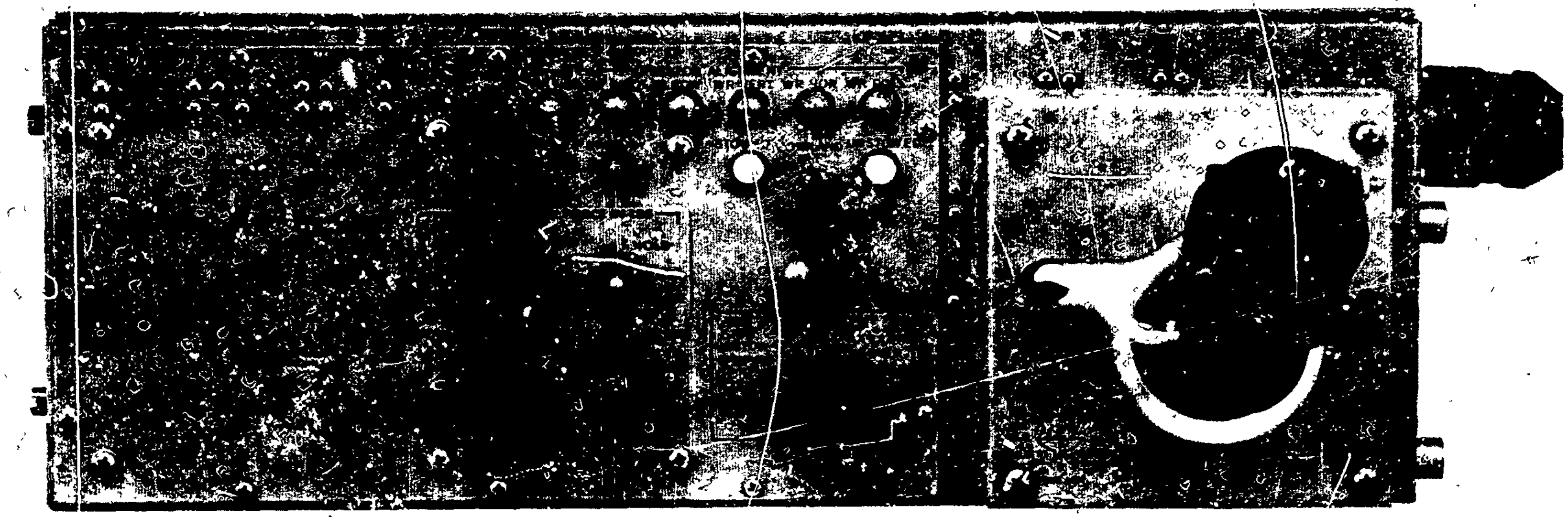


Figure 9. DSRV Manipulator Control Input Device

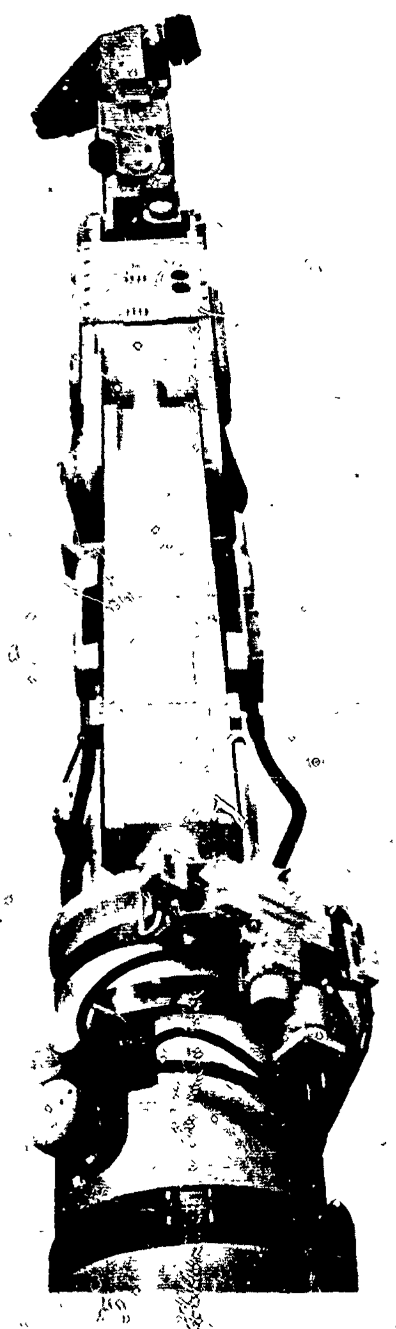


Figure 10. DSRV Manipulator with Terminal Device

SUBMERSIBLE MACHINERY & DEEP OCEAN TECHNOLOGY PROGRAM

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ABSTRACT

Submersible machinery is considered to be those equipments that must operate either flooded with sea water or filled with an insulating medium at submergence pressure and temperature. The need for submersible machinery was generated by the development of deep submersible vehicles. These vehicles were originally intended to permit ocean exploration. The Navy's interest is to extend the applicability of these vehicles to include surveillance, rescue, salvage, etc., operations. The absence of experience and guidelines in the design of machinery for submerged operation resulted in unanticipated problems in reliability. There is little in the way of detailed documentation relative to the nature of the problem, however, operational reports indicate that failure of electrical components have resulted in long hours of maintenance to obtain short mission capability. Therefore, the major effort in the Navy's Deep Ocean Technology Program has been to establish a state-of-the-art base line. Evaluation indicates that systems and components in existing submersed application are marginally acceptable. Consequently, considerable data is being documented relative to the nature and mechanics of failures being experienced in the evaluation process. This information will be used in the formulation of specification for a new generation of submersible machinery.

The auxiliary, propulsion and electrical machinery systems technologies in support of the U. S. Navy's ocean engineering effort encompass a broad spectrum. They are considered to include not only the specific tasks in support of the deep submersible program but the related technological efforts in support of the submarine and other programs. The challenge of harnessing the major technological advances of the space age and applying this machinery potential to the exploitation of the ocean will result in effective ocean engineering programs. In general, it is considered mandatory to advance machinery components and subsystems simultaneously with the advancement of the basic technology as related to the ocean environment. While most existing systems & components have met, with reasonable success, the past and present relatively primitive needs of submersible design, many significant problems remain to be solved before adequate systems for future vessels can be assured.

One of the most urgent requirements is the development of a pump capable of operating at a differential head pressure at deep depths. As can be expected, pumps operating at depths of 20,000 feet and differential head pressures of the order of 9,000 PSI require major developmental work in order to achieve the requisite capacities and the necessary reliabilities in spite of the difficulties of a salt water environment. Two 3,000 PSI units have been built (Fig 1) and are in the final testing phase. A 9,000 PSI unit is in the design phase. All of these units will incorporate ceramic pistons and cylinder liners in one form or another. Initial tests have strongly indicated that the new high tensile ceramics and plasma-sprayed ceramics are totally impervious to the normally deleterious effects of seawater on metal piston type pumps.

The development of deep submergence vehicle electrical power systems has until now followed the pattern of previous marine systems. Such systems typically have separated vessel propulsion power requirements from the other ships auxiliary loads, supplying each separately through individual switching equipment and using separate power conditioning equipment when necessary. For optimum system effectiveness it appears that there are advantages in an integrated approach to design. It is planned to analyze a typical system from this standpoint. For such an analysis method to prove effective it is essential that the characteristics of all critical loads such as the propulsion motors, be evaluated together, with all the electrical system. Only in this manner will the optimum total vehicle system concept result as the basis for a sound development program.

Fig. 2 illustrates model system block diagram the subsystems for a submersible electrical and hydraulic system. The power input is shown at the left and the output functions are shown on the right. The propulsion systems components indicated, comprise the power source, motor, controller, hydraulics subsystem, speed reducers and the thrust system. The overall system must be reliable and satisfy vehicle requirements. Components must be capable of load transients as well as pressure cycle fatigue. Whereas, motors and controllers are being developed to provide for part load operation and motor reversals, controllable pitch propellers provide many advantages in terms of a simplified electric propulsion system.

Submersible electric drives

The wide variety of undersea vehicles, work equipments and habitats being planned and developed by the Navy and the non-military ocean community require equipment to convert electrical energy to mechanical power. This includes drive systems for such functions as propulsion and maneuvering, hydraulic systems, pumps, actuators, etc. Most of this machinery will typically be located in the high-pressure, seawater environment outside the personnel hull. Where necessary, pressure protecting enclosures can be used to house pressure sensitive equipment particularly electronics. Seawater contamination, carbon formation due to arcing and fluid material compatibility are major problems in oil filled, pressure equalized containments. Elimination of causes of contamination and fluid filtration and monitoring techniques are required. Fig 3 illustrates a typical pressure compensated machinery system. Today most of the available drive systems are the result of adapting equipment intended for operation in normal air environment. In most cases, they have been used because of the urgency of the need and as a result, they have not fully satisfied the performance reliability or efficiency requirements. In many cases, the operational performance parameters have been derated and contain design requirements such as ease of maintenance and service life have been compromised.

The deep ocean technology program has established an electric drive (4) systems task with the following specific objectives:

To procure and evaluate selected alternatives to motor controllers, motors, and speed reducers in drive system configurations.

To identify problems and common technical deficiencies.

To provide design data and rationale for specification recommendations for future electric drive systems.

The program includes basic state-of-art hardware which is augmented by a basic technology development. This program will provide a technology base for developing advanced systems.

Fig. 4 is an overlook of the submersible electric drive systems program. It includes a range of DC and AC motors with their associated controls and transmission systems as illustrated. The program includes shunt and series wound DC motors with a variety of transmission systems as well as a variety of squirrel cage AC, salt water and oil compensated motors and inverters. The salt water flooded motors are direct drive at 600 RPM. The following conclusions can be drawn as a basis for the ongoing effort:

a. Considerable development work is required before reliable off the shelf components are available.

b. DC machinery commutators are critical when operated in oil at high pressures; however, reasonable success has been obtained on one unit for short operating periods. It has been found that with extra attention to motor design for improved commutation, narrow brush width, and adequate brush pressure, a DC motor can be operated in a low viscosity oil for 500 hours or more with acceptable decomposition of the compensating oil and deterioration of the commutator surface. This approach has produced workable propulsion designs with minimum design and manufacturing development since a wealth of DC motor equipment design information and experience is available from other industrial fields. Additional effort on the commutation problem is planned.

c. Encapsulation of equipment can solve many of the electrical and the environmental problems; however, seals and penetrators require additional effort to preclude salt water contamination of the compensating fluid.

d. Speed control for DC motors is most efficiently accomplished by solid state chopper circuits which modulate the battery voltage. Fluid filled pressure compensated controllers have undergone pressure cycle fatigue tests with some success. Improved logic circuits are required for protection of semiconductors against the transient peak currents and voltages of actual operating situations.

e. Sea water flooded AC motors with coated windings and parts, or encapsulated stators, have been tested. Coating technology used will enhance performance life of motors operating with salt water contaminated compensating fluid. These 600 RPM motors may be satisfactory for thrusters but lubrication of speed reducers will be a problem for lower RPM motors.

f. An advanced AC synchronous motor with an induced salient pole rotor, excited by a stationary field winding has undergone preliminary tests with indication of 10-15% higher efficiency than other systems. Development of this concept will be continued. Controller problems have delayed evaluation of the motor. Inverter weights for any AC system are critical and must be reduced (possibly by pressure compensated packaging).

The most successful developmental drive system to date is shown in Fig.5 composed of a 17 HP DC motor with 250 hours of test time. A traction drive with net output of 15 HP has been tested 130 hours with limited reversals. This system used a solid state chopper type controller. Weight of this system compares favorably with all other systems.

Within the next 8 months considerable additional experience should be obtained with the various systems. This experience will provide a better base for comparative evaluation of the AC-DC systems. A number of proprietory advanced concepts for extension of the technology are under consideration and will be undertaken pending results of present tests.

A deep submergence vehicle depends upon its electrical power system for all vital functions. Reliability commensurate with this dependence must be insured in spite of the fact, that, for critical weight considerations, most of the electrical system components must be installed outside the pressure hull.

The history of electrical installations for deep vehicles has been one of the adaptation of conventional system concepts and hardware long used for surface ships and combatant submarines to a hostile foreign environment. In some instances assembly and manufacturing procedures have required "quick fix" techniques to meet construction schedules. Too many of these quick fixes have become accepted procedures and have resulted in assembly methods that are not automatically reproducible and extremely costly in the administration of a quality control program.

Motors, contactors, and fuses have been immersed in insulating oil, equalized to sea pressure, and have functioned with some success. Unfortunately oils at high pressure are subject to accelerated decomposition in the presence of arcing and the performance of commutator motors and switch contacts is disappointing and maintenance is high. The failure by burnout of a length of cable on the Trieste recently has attributed to failure of a fuse in an oil envelopment. The hazard of salt water contamination of the insulating oil is a continuing problem because of the failure of seals.

The most common failure encountered in the outboard application of cables has been conductor breakage which has been traced to two causes. First - the conductors do not have sufficient physical strength to withstand normal handling during cable assembly fabrication and installation. Second - the conductors move in a pistoning manner inside the outer jacket because of external pressure. The slack conductor knuckles at the connector or other terminating point and causes fatigue and breakage after a relatively few pressure cycles. The fixes that have been developed for each are costly and require close quality control.

Circuit breakers and fuses are the principal components for isolation of faults and overload protection, and are applied in an electrical distribution system to provide the maximum in continuity of service.

Faults and overloads are sensed with thermal or magnet devices and there is no really valid information available relative to the changes in the time-current characteristics of these devices when immersed in a fluid at submerged temperature and pressures. There is some indication that the degradation has some relationship to time, therefore, efforts are being made to obtain reliable application data.

Penetrators and terminal connectors designed for combatant submarine application are basically used for low wattage and voltage circuits. Penetrators for application in deep vehicle electrical distribution and battery systems are generally required to include relatively high wattage power circuits at system voltage. Therefore, submarine penetrator technology is not directly applicable to vehicle penetrator designs.

A two phase contract has been awarded for the design and testing of penetrators and dry terminal connectors suitable for 20,000 foot application. The first phase constituting a survey of the state-of-the-art has been completed. Phase two, for the design, fabrication and testing of a limited number of penetrator configurations.

One of the most urgently needed components is an underwater connect and disconnect device (wet connector). Presently available wet connectors are usable on low voltage circuits, but are not reliable at distribution system voltages. New designs that have been proposed are extremely complicated and difficult for divers to manage. This device is needed for relamping of lights, and to provide means for servicing camera and TVs mounted bottom side on vehicles. Specifications have been completed and contractual efforts are presently in progress to develop a suitable wet connector.

The existing cable project has investigated conductor material and (5) design, insulations, fillers, jacket materials, cable core configuration, transmission characteristics etc. Based on these investigations several cable designs have been developed which are now under procurement.

Particular emphasis will be placed on correlation of test results with specific inspection techniques and quality control procedures. The flex and fatigue testing of a complete subsystem of cables, penetrators and connectors is considered mandatory because of previous interface problems between these components. The effective use of penetrators dictates the need for multi-purpose cable designs. A program is planned where individually insulated and jacketed, single conductor, shielded pairs, coax cable, etc. would be developed and applied to suit the vehicle system design. Conduit will provide mechanical protection in a free flooding arrangement. It is considered that this approach will remedy some of the major problems presently encountered with existing cables.

The planned approach to advancing the electrical power control technology is largely predicted on the utilization of the advancing solid state, integrated circuit technology. In an electronic control and fault protective system, as contrasted with a conventional design using electromechanical and thermal devices, it becomes practical to employ more sophisticated fault detection and logic functions. This approach will lead to an integrated more reliable power system. Whereas the present program includes development and evaluation of advanced electromechanical designs the prospects of success are believed to favor the electronic technology. It is realized that the enclosure of the electrical control system presents problems different from that of the power system. There is a greater possibility that the design of the low power logic, utilizing integrated circuits, will not lend itself to sea pressure operating conditions. In this case, it will probably be more practical to provide hard shell enclosures for the control system components. Because of the smaller volume of control components it is not expected that this will result in appreciable penalty in weight. It is planned to develop the criteria for the hard shell technology for these components.

Based on the objectives and technical emphasis outlined, the present program for fluid compensated systems, switches, circuit breakers, fuses, and junction boxes has resulted in the following conclusions:

a. Experimental investigations have shown that at high pressure both silicone and petroleum oils show greatly accelerated decomposition under arcing conditions. Solid carbon blocks form between contacts (2) after a few cycles..(See Fig 6). A major improvement results by using low viscosity compensating fluids.

b. Deposits of carbon over fuse elements, after short term application in oil under load and pressure alter the fuse rating. The increase of viscosity with pressure causes major problems in design of oil immersed mechanical circuit breakers. For this reason conventional devices can be used only with caution, allowing for the substantial alteration of their in-air characteristics.

(1)

c. A low capacity, four amp, solid state switch device has been successfully breadboarded. This technology is being extended to a 100 amp design. This appears to be a satisfactory approach to increasing capacity of this type device. The four amp switch has operated successfully in compensating fluid at 6000 PSI pressure for 50,000 circuit interruptions demonstrating the feasibility of this approach.

d. Compressibility of fluid has an effect on electrical component performance especially in those instances where arcing is a characteristic.

e. Seawater contamination has a degrading effect on insulating quality and a major reduction in life of ball bearings.

f. There is no single fluid suitable for all applications nor is it planned to undertake such a development.

g. An improvement in testing techniques and devices is required to improve validity of results as related to actual operating conditions. (i.e. overload detection devices necessary for circuit breaker development).

h. Sufficient data has not been obtained to establish a maximum acceptable degree of contamination or the rate of degradation of fluids in an actual systems environment. Considerable additional basic fluids and insulating materials research is required.3 This effort needs to be augmented with subsystem compatibility tests.

i. Instrumentation and criteria for monitoring techniques for critical components affecting vehicle safety require considerable additional development. Specifically pressure monitoring and pressure relief techniques within compensated systems are required to preclude failure of major components that might affect vehicle safety.

In considering the future program, experience with the deep submergence installations in service, emphasizes the need for the development of electrical systems and components of high reliability and improved performance. Such development must be based on continuing analysis of the complete vehicle system. The current state-of-the-art of applications of silicon solid state devices is sufficiently advanced that virtually no effort should be required in basic circuits or devices. For example, aero-space applications using solid state switching rather than mechanical switches and breakers are now being used. Solid state inverters of suitable size and rating also are available. In each case, it is evident that the necessary adaptation for deep submergence application must be made and performance must be confirmed by extensive testing before certification for manned vehicle applications will be possible. The maximum advantage in the use of solid state devices will be possible only as packaging can be provided for their application to at least 20,000 foot depth. A program to design and build specialized semiconductor packages, both of power types and integrated styles will greatly increase reliability. It is expected that this will be accomplished by insuring isolation of the active semiconductor structure from pressure strain effects. The use of semiconductor devices in high pressure environments requires that other circuit components such as resistors and capacitors also be developed for the same conditions. This program is expected to be of less difficulty but must be carried along in parallel, if the system applications are to be successful. One potentially attractive solution to the power distribution and switching problems in high pressure ambients is the use of solid state inverters to energize an AC system using all solid state switching devices. If, with this type system, high efficiency AC induction motors are used, the problems associated with DC motors and oil decomposition under arcing conditions can be completely eliminated. One of the most significant of the potential advantages is reduction of total system weight and space by the choice of optimum voltage and frequency. In the area of cables and penetrators, smaller cable size for main power circuits and the use of multiplex techniques for signal functions has the possibility of major simplification in cabling installation and the elimination or reduction in size of many of the penetrators. Each of these factors will have a cost advantage as well as an improved performance contribution. Based upon the results of laboratory tests conducted on the engineering prototype system, preliminary specifications criteria will be prepared for the required components. Service evaluation of the performance of equipment built to those specifications will provide a criteria for final component procurement specifications and/or certification.

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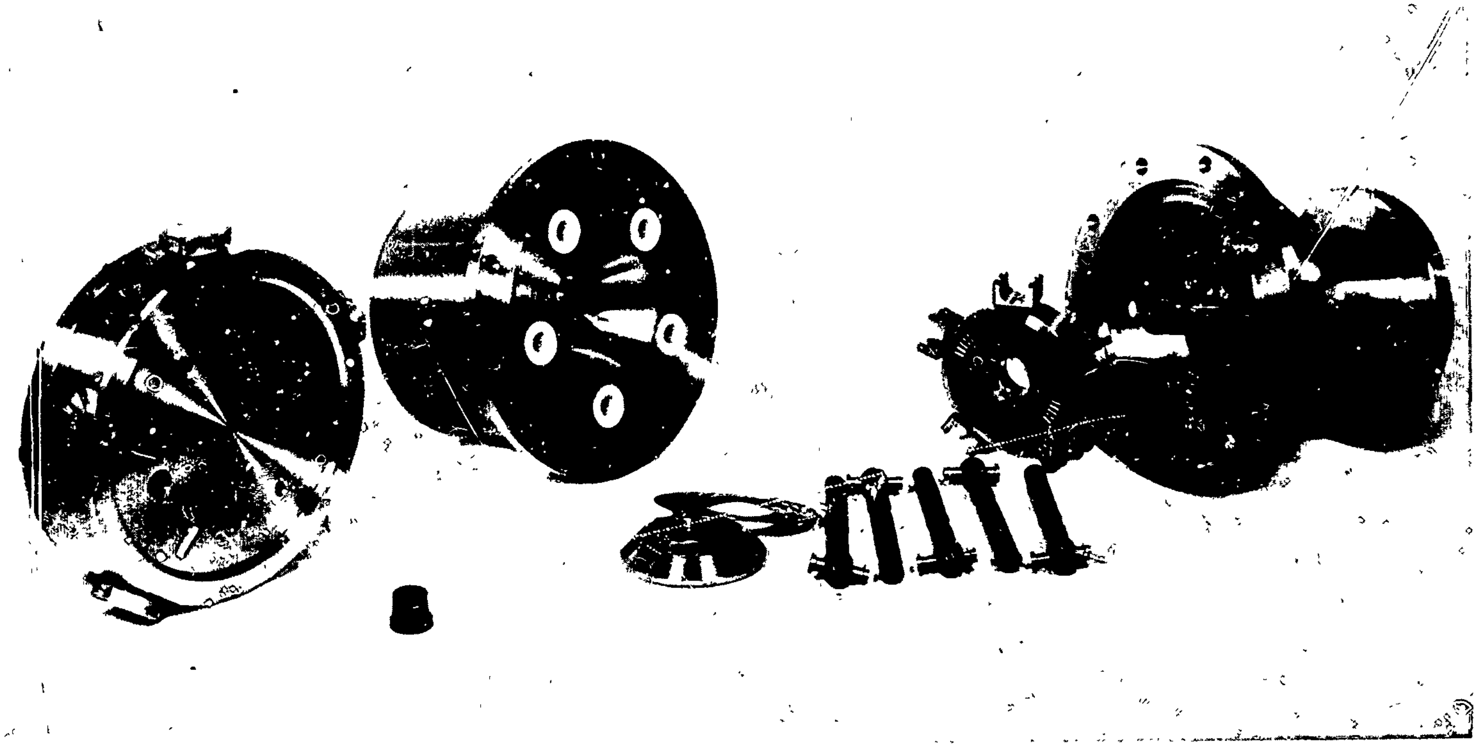

Figure 1

Differential Head Pump with Ceramic Pistons and Cylinder Liners

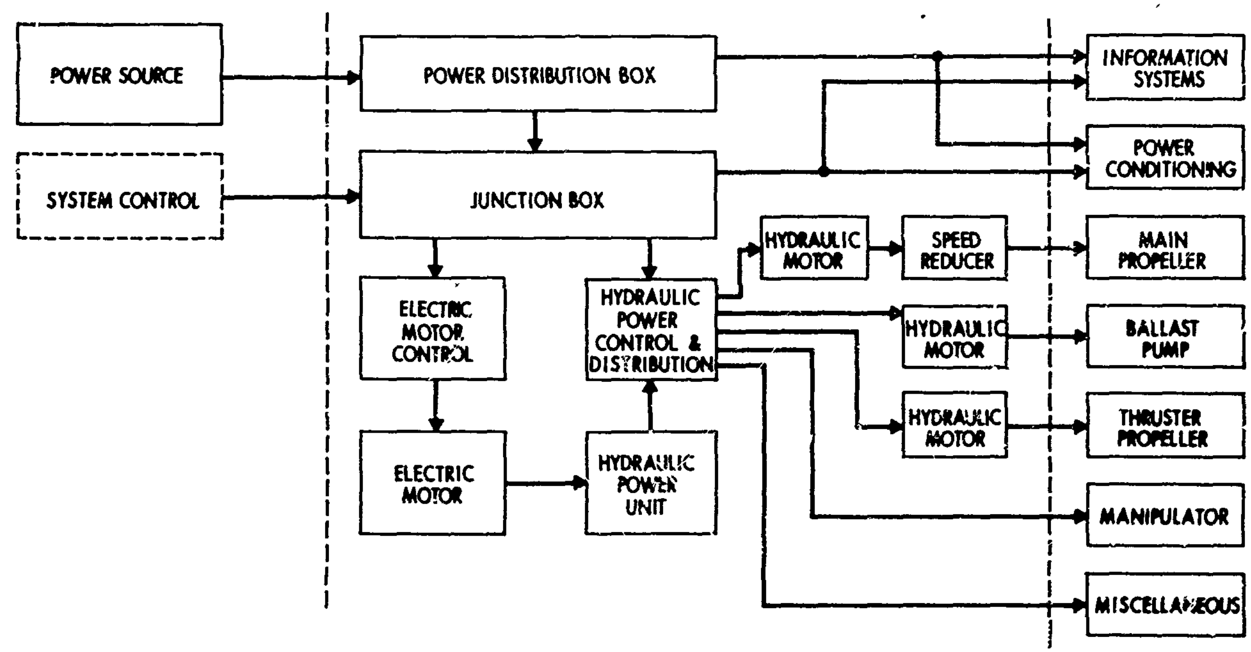

Figure 2

MODEL SYSTEM BLOCK DIAGRAM

SUBMERSIBLE ELECTRICAL AND HYDRAULIC SYSTEM

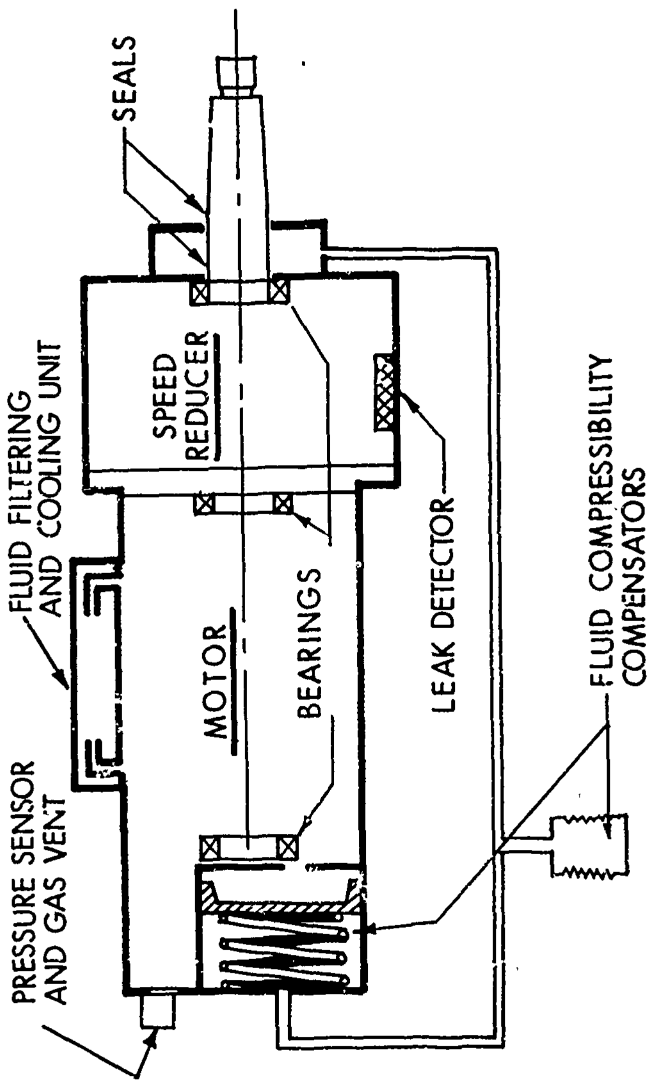

Figure 3

TYPICAL FLUID ENCAPSULATED MACHINERY SYSTEM

DOT · SUBMERSIBLE DRIVE SYSTEM UNITS

MOTORS	CONTROLS	TRANSMISSIONS
3 hp, dc, Shunt, 3300 rpm Bread'bd AIR		
17 hp, dc, Shunt, 3000 rpm Prototype 6081 OIL	Chopper Control-Bread'bd AIR	Planetary Gear 3300/60 rpm 6081 OIL
17 hp, dc, Shunt, 3000 rpm Advanced	Chopper Control-Hardshell AIR	Traction Drive 3000/90 rpm 6081 OIL
7.5 hp, dc, Series, 3600 rpm Hoover Fluid	Chopper Control Si Oil	Single Stage Reduction Gear Hoover Fluid
7.5 hp, 3Ø, 30 Hz, 600 rpm — Canned Si oil-filled stator SW	Inverter-Variable Voltage & Frequency, (Carter) Si Oil	DIRECT DRIVE
7.5 hp, 3Ø, 30 Hz, 600 rpm — Canned Epoxy-filled stator 5606 OIL		
7.5 hp, 3Ø, 30 Hz, 600 rpm — Free-Flooded SW		
12 hp, 3Ø, 400 Hz, 3600 rpm		Harmonic Drive 3600 / 150 rpm,
15 hp, 3Ø, 60 Hz, 1750 rpm -	Inverter-Variable Voltage & Frequency, Hardshell AIR	Two Stage Reduction Gear
18 hp, NADYNE, Brushless Motor & Control Si OIL		Planetary Gear 3600/90 rpm - Si Oil

Figure 4

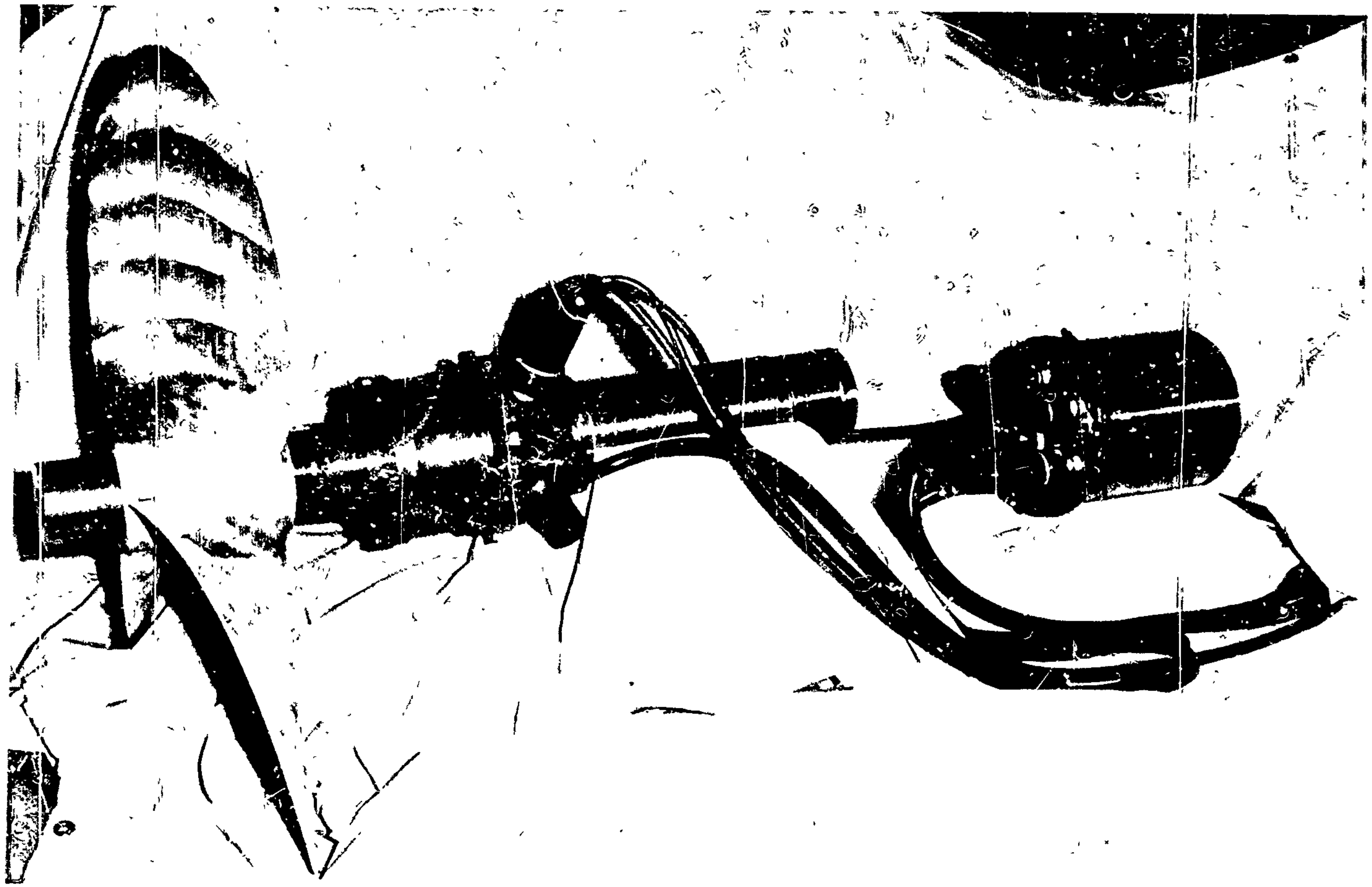

Figure 5

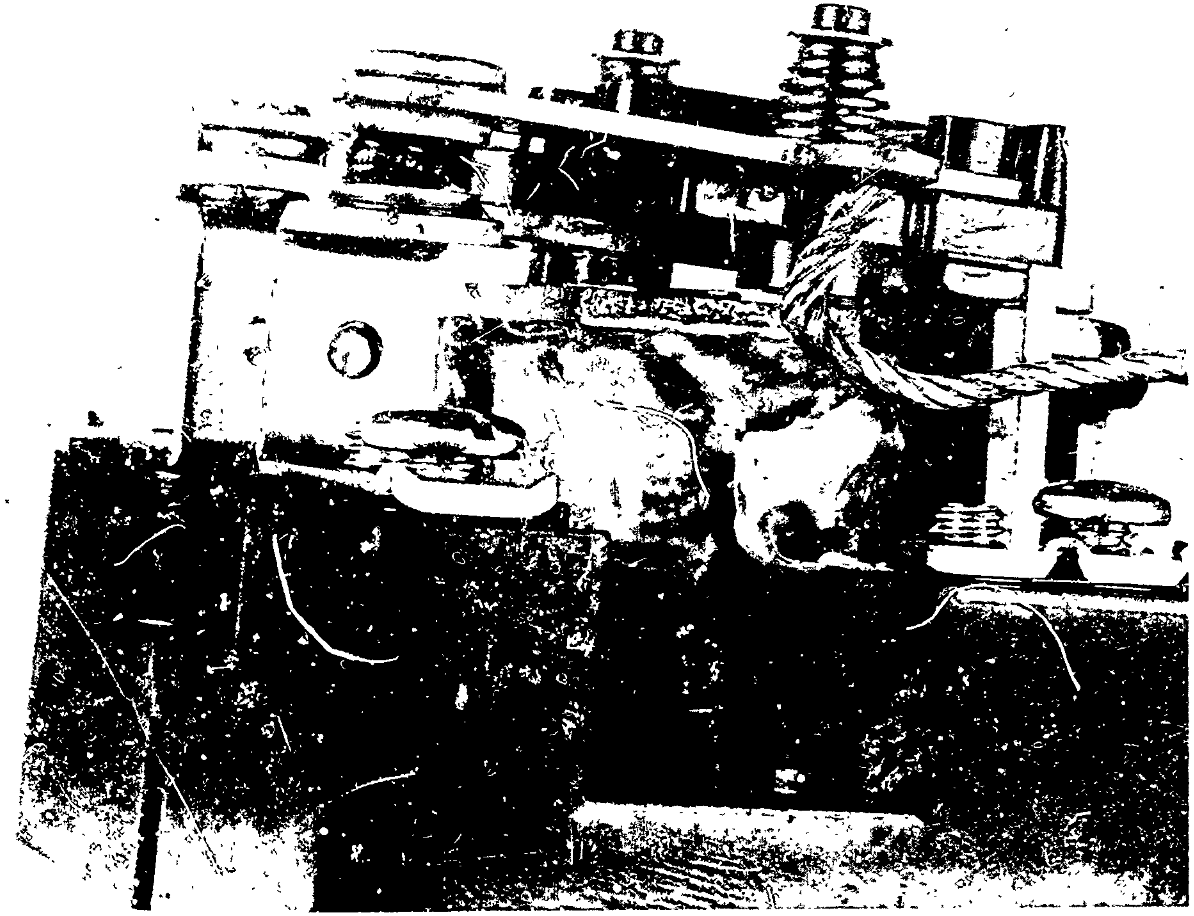

Figure 6
Electrical Contactor after 5 Operations in Oil Medium at 5000 PSI Pressure

SUBMERSIBLE VEHICLE MACHINERY OPERATIONAL PROBLEMS

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ABSTRACT

Each submersible in operation today is a unique machinery system with unique capabilities—in fact, a prototype. Development of components used in the systems, in some cases, has advanced the state of the art but reliability of the subsystem is not readily achieved. Thus, operational problems may be generated and only by constantly upgrading and applying lessons learned can we hope to make prototype systems operational systems.

"Work tools" such as manipulators, cameras, and other instrumentation systems make useful work by a submersible possible. However, because they are subsystems and not part of the original submersible system, interface problems frequently occur and considerable effort must be expended in solving them.

INTRODUCTION

In 1966, the first of many submersibles developed by private industry, "Deepstar 4000" was introduced for use in oceanographic and ocean engineering applications.(1) Each of the Deep Submersible Vehicles (DSV) has been designed to provide an improved capability, either in depth or in a specific orientation. By this method, new systems have been introduced to enhance the capability of the DSV, often resulting in further modifications as the DSV system is exposed to operational useage.

A system integration technique is now being employed, but all too often additional component requirements are added by the user and integrated into an existing system. This can result in unreliable operation of the basic DSV system and may defeat the original advanced design concept sought. The engineering changes defeat the initial integrated concept, and usually at larger cost with a degraded utilization.

DISCUSSIONS

Each DSV in existence today was designed to achieve a variety of improvements over the previous DSV's. It can be readily acknowledged that a DSV of multiple capabilities and improved performance characteristics becomes a more marketable commodity. Unfortunately, a DSV to one user is not the same to another, due to the variable mission requirements imposed. Obviously then, each manufacturer attempts to consolidate a multiple mission DSV with every conceivable "work tool" available to the user. What is actually considered "work tools" are: viewing lights, camera and strobe, a manipulator and a voice tape recorder within the sphere. These tools are envisioned as the basic suite which hopefully will provide a basic capability. The systems are designed for this type of operation. The manipulator, for example, may be very sophisticated on one DSV and by its development represent a substantial capital investment. Based on this high cost item, the remaining tools may not be of the same advanced state of the art. The systems are designed to accomodate these features only. This concept then introduces the system failures and low reliability if any additional items are added, because overriding is the cost factor of providing a transportable, highly maneuverable DSV.

It is not the intent of this paper to pinpoint manufacturer weaknesses in any of the existing systems, but to point out the "booby traps" we have all become victim to.

Superior numbers in parentheses refer to similarly numbered references at the end of this paper.

DESIGN PARAMETERS

It is reasonable to assume that before the first line of a design is committed to paper, an analysis of "what" is required of the DSV be established. The common approach, then, is what we call a "mission profile." To be sure we have done our homework properly, we utilize the marketing department and contact all known potential users by mailing out questionnaires and by making personal contacts. From this we construct a matrix. (Figure (1)). This conglomerate of information is used as our design parameter. To satisfy our matrix, we could build a DSV of such complexity that it would never get wet, so, in good design practice, we do a trade-off study and eliminate those features not felt essential by the engineers. The engineers are not overly impressed, perhaps, or knowledgeable of some of the scientific applications, so, many of the requirements are eliminated. Or, they may feel certain features may be added at a later time. Budgets are set; and we now commit to paper the DSV of optimum useage.

DESIGN

The object, of course, is to construct our DSV so that new materials have maximum utilization to minimize weight and maintain a small enough envelope so that we have a useable system at sea.(2) Support at sea will be determined only after we have sized the vehicle. Our initial matrix is no longer used as it was only a tool to sell management, and the configuration is set by the mechanical design department. Unfortunately, in the systems department—electrical, hydraulic, etc., a DSV of different proportions is in the making. Eventually the two groups (mechanical and system) meet on the Bubble Chart (Figure (2)) as we introduce the system integration group. At this time we discover two different DSV concepts (Figure (3)).

At this stage on our Bubble Chart we have a complete halt as we now revise our total plan and do further trade-offs to satisfy both design groups. The result is a DSV that will go to 9,121 feet, have an arm, viewport and motors (Figure (4)), and weigh 11 tons. This design discussion obviously reflects exaggeration, but compromise in design is an accomplished fact. At this time we are prepared to investigate the mystic as some manufacturers say of the "certification process." This certification does require documentation, testing and proof that our DSV is going to be a safe submersible. The certification process does offer a good basic engineering design manual adaptable to all DSVs. Through this mechanism we are able to introduce new state-of-the-art in components, systems and materials. For example, a new solid state inverter for our electrical system will go through this process. We are now ready to proceed into final design. Our new electrical system—solid state, remains; our light weight materials are utilized; the state of the art has moved forward. Unfortunately, the DSV, as built, no longer meets the original or revised mission profiles, but does provide a capability to attain a depth not available in an existing, transportable DSV. This has come about due to our trade-off study. We have developed a well-designed and balanced system. Our solid state inverter occupies less space and provides our full hotel power compliment (Figure (5)). Our mechanical arm utilizes hydraulics and provides full motion in every aspect. Our motors are AC and floodable. During our check out, diverse minor deficiencies have been noted and are in correction.

MARKETING

The marketing man's job is to make the vehicle known to all potential users and offer its virtues as the ultimate. The minor problems of the vehicle are discussed as common to any new concept, and all is well. The original mission profile established for DSV concept came from the marketing department, so, obviously it now can do all things. A contract is established and the mission profiles now can be accomplished. We should recognize that the cost per dive must be reasonable, especially with todays sparse budgets, and that even though a DSV may be ultimate, its dive cost may preclude any utilization.

UTILIZATION OF THE DSV

The many mission profiles that could be imagined now become a reality. For this discussion we will limit the profiles under the broad category of science. As can easily be imagined, instruments for control and recording will be required in the pressure sphere. External to the submersible will be the data gathering instruments of all sizes and description. As the planning and location of these scientific packages now become a reality, we discover that within the pressure sphere, space is limited or almost nonexistent. Externally there is no real provision to attach data collecting instruments and the re-re-engineering of the DSV begins. This is necessary to make it a useful tool. It should be understood that a DSV is just another tool available for investigation, and not the principle factor around which a scientific program is planned.

We now introduce another type of engineer, not yet named, but unique in capability, because it is he who must bridge the gap between the scientific investigator and the system engineer of the DSV. He must develop, first, a rapport with the investigator to fully understand the scientific mission profile, and then, solve how this is to be accomplished by the DSV. As can readily be seen, he must understand the DSV systems and devise a satisfactory solution to satisfy both parties concerned. As an example, let us recall the advanced solid state inverter. Our inverter held 50 cups of electricals and now we look to it again to provide the additional power required (Figure (6)). If we insist, then the inverter obviously will not perform; but what if we eliminate or modify one or more of the DSV "work tools," then there will be sufficient electricals for all! At this point we introduce a Gremlin into our finely designed, integrated electrical system. As an example, we eliminate the camera system and in turn have seven cups of electricals available. Into the system we add a scientific data collection system that requires seven cups of electricals and feel confident that all is well. We ignore the fact that perhaps we may introduce overloads or malfunctions in the added system, and the result is an inverter problem. Conversely, the DSV system may introduce an unstable supply of electricals to our data system. Any electrical component failure in this bastardized system, DSV or scientific, causes a failure and our solid state inverter is in trouble. A machinery failure in the sea! How can we hope to resolve these problems? First, we must add a minimum capacity of at least 25% to our inverter. We should also recognize the potential of ground loops, spikes in our normal true sine waves. Therefore, in many applications we should have sufficient battery capacity of 28-32 volts to drive another inverter for specialized useage.

External to the submersible we construct brows[1] and various appendages that soon turn our DSV into the Medusa that was envisioned earlier by the Systems Group. Strain is injected into the basic DSV hull structure, vehicle handling characteristics change, and we introduce new potential machinery failures.

What lessons in general have we learned in four years of operations? We can recommend for the future some of the following to eliminate further failures:

1. DC 28-32 volt battery supply in excess of hotel power requirements.

2. Static inverters, one for hotel and one of a smaller capacity for general useage. Each system independent to eliminate spikes and random noise.

3. Recognize that additional hull penetrations are required, and connectors external to the pressure sphere for specialized additional scientific or work tools.

4. Provide for external attachment to the DSV for instrument packings.

5. Provide adequate vision, overlapping for the investigator and pilot. In-situ exceeds television for a majority of investigations.

6. Provide internal in the pressure sphere rack space sufficient to take on additional tasks.

7. If we use a navagational system, make it simple so if a component failure in this system occurs, the mission profile may still be carried out.

8. Even though support ships are not dealt with in this paper, provide an adequate system that will give maximum utilization of the DSV.

These are but a few, and it is recognized that mission profiles vary; but, in general, there are always additional tools that the investigator will use.

It becomes rather obvious that: man, not the machine, is the cause of failure. Equipments and systems can only perform as they were designed and tested. They are not human and cannot adapt to change. We, the users-designers, in attempting to attain the ultimate all the time, are the cause of failures. Our excuses may be budgetary, and justly so, but this does not excuse any of us from not employing sound engineering practice, which simply is: that each machine, system, or component has a designed and built-in performance characteristic. Exceed this boundary and machinery or mission failure is our product.

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80,000 FT ALL-PURPOSE DSV

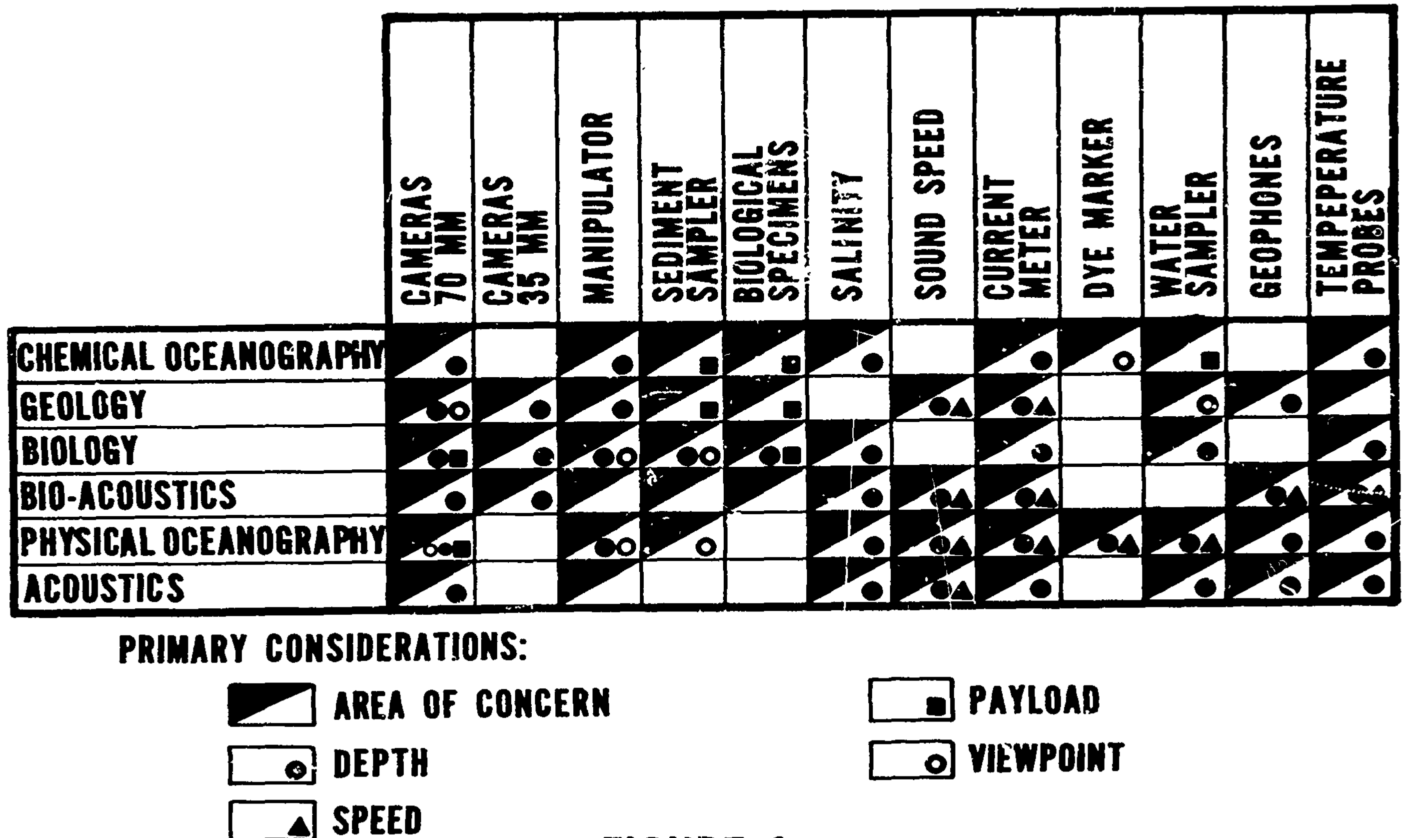


FIGURE 1

NOC

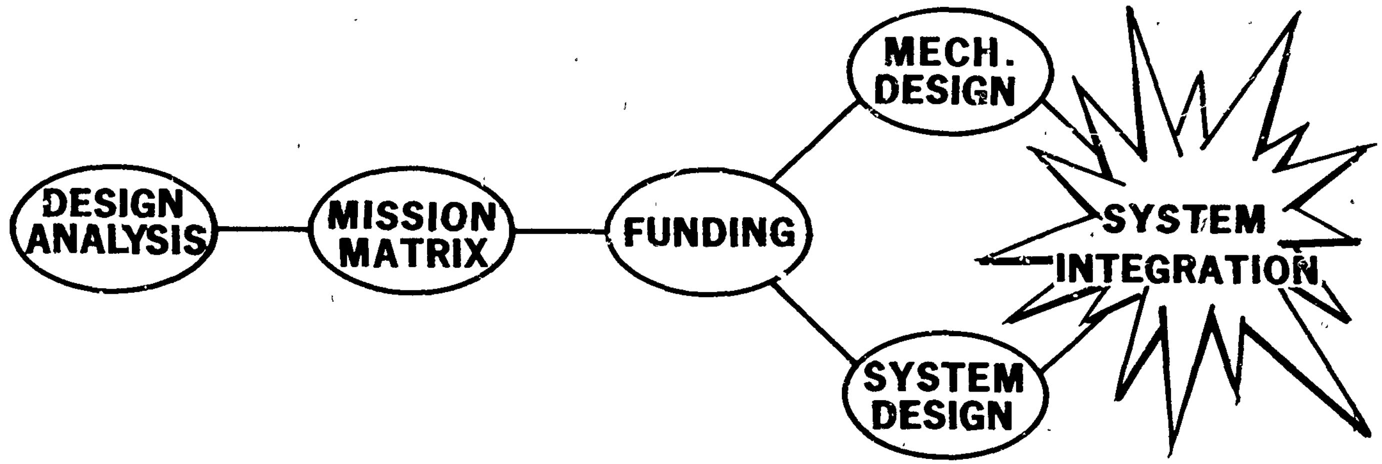
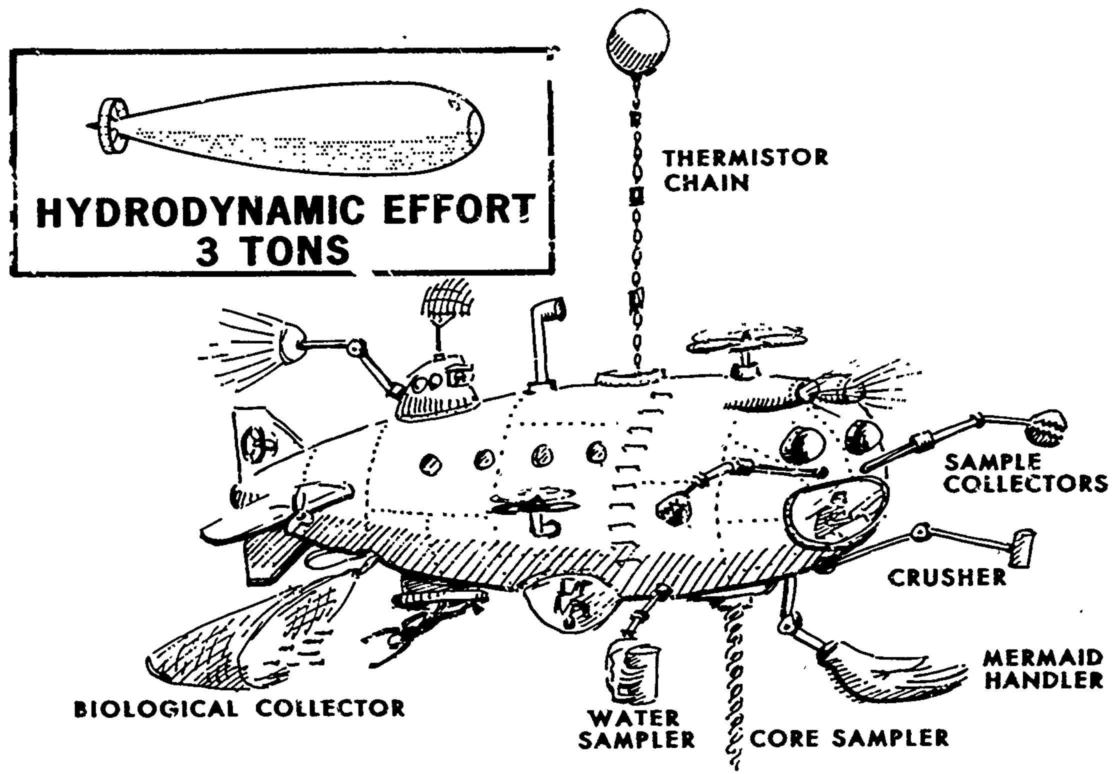

DESIGN ANALYSIS
MISSION MATRIX
FUNDING
MECH. DESIGN
SYSTEM DESIGN
SYSTEM INTEGRATION

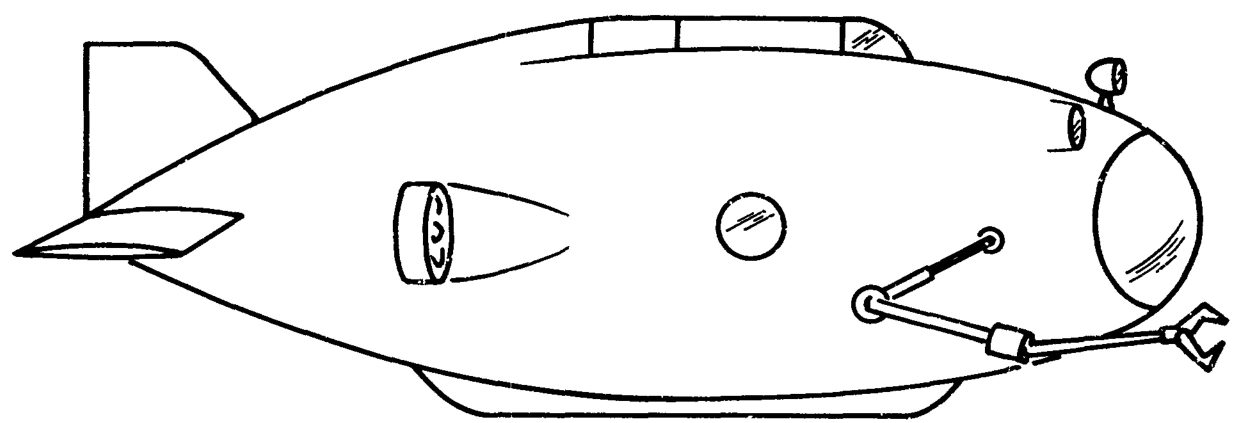
FIGURE 2



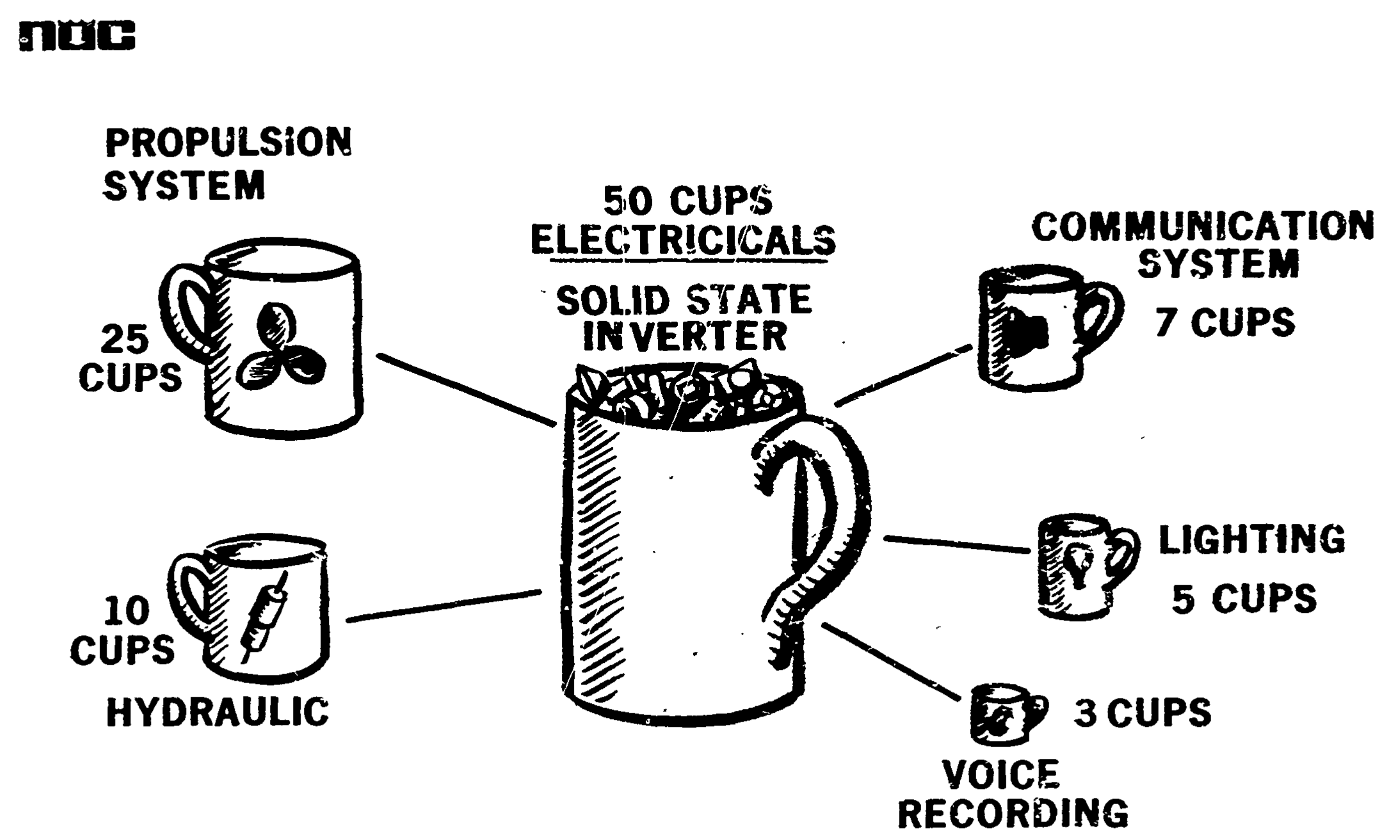
SYSTEMS GROUP CONCEPT - 60 TONS

FIGURE 3

NUC



9,121 FEET — 11 TONS
FIGURE 4



NOC
PROPULSION SYSTEM
25 CUPS
10 CUPS
HYDRAULIC
50 CUPS
ELECTRICICALS
SOLID STATE INVERTER
COMMUNICATION SYSTEM
7 CUPS
LIGHTING
5 CUPS
3 CUPS
VOICE RECORDING

FIGURE 5

ELECTRICAL BLIVET
FIGURE 6

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A. ABSTRACT

In recent years, emphasis has been placed on deep ocean areas as an operating environment for the United States naval forces. All Navy experiences to date indicate the extreme importance of careful testing of men and equipment in hyperbaric facilities prior to actually undertaking the operation in the ocean environment. In addition, hyperbaric facilities have been extensively utilized for medical treatment.

The requirement for larger sizes of hyperbaric chambers and higher pressures, as well as the involvement of personnel as occupants and operators of hyperbaric facilities make it mandatory to take all necessary precautions to avoid accidents or incidents and to provide for casualty recovery.

This paper outlines the requirements that should be met during the material adequacy process of hyperbaric facilities.

B. INTRODUCTION

The basic purpose of this paper is to describe the material adequacy requirements of new man-rated hyperbaric facilities — shore-based decompression/recompression facilities including wet pots (Fig. 1) — and deep-ocean-simulation pressure chamber complexes for testing equipment (Fig. 2&2a) or for testing man and equipment together (Fig. 3).

During the material adequacy or material safety process an independent review is made to ensure, within the existing state of the art, that design, fabrication, testing, construction, inspection, maintenance, and operation of the various systems, sub-systems, components, and portions of the facility are in accordance with sound and acceptable engineering principles. The material adequacy process has a dual purpose: (a) to safeguard the life of the individuals - operators of the facility and occupants of the chamber - during a simulated dive condition, and (b) to provide for casualty recovery during an accident or incident.

NAVSHIPS material adequacy philosophy of manned non-combatant submersibles is adopted and applied to hyperbaric facilities in this paper.

C. THE ENVELOPE OF SAFETY REQUIREMENTS

The safety effort of a hyperbaric facility depends upon the following areas:

1. Mission and Operational Control
2. Competency of facility operators
3. Competency of chamber occupants
4. Material adequacy

The certification of areas 1, 2, and 3 is the responsibility of the operating agency. It is the responsibility of the Material Certification Authority to obtain the maximum confidence for material adequacy through established requirements of adequate control and proper documentation.

D. MATERIAL ADEQUACY PROCEDURE

The Program Cost Estimate (PCE), or a similar document prepared during the early stages of conception of a hyperbaric facility, should invoke the NAVSHIP-NAVFAC document of May 1970, entitled "Hyperbaric Facilities, General Requirements for Material Certification". The material adequacy process starts from the time the applicant requests material certification from the Material Certification Authority which is represented at this stage by a Material Certification Project Engineer. Subsequently, the general milestones are as follows:

1. Material Adequacy Scope

The applicant submits to the Material Certification Authority a material adequacy scope for negotiation. This scope includes the envelope of all systems, sub-systems, components, and portions of the facility (Fig. 4) which are needed to maintain operators and occupants and to provide for casualty recovery capabilities, e.g. to return occupants safely to a normal, one atmosphere environment. In addition, a check list of items using a "Pre-survey Outline Booklet for Hyperbaric Facilities" is prepared.

Items which may be included in this list are the following:

a. Materials and their application
b. Pressure retaining envelope
c. Supports and foundations
d. Appurtances - Hatches, viewports, penetrations, etc.
e. Piping and hoses
f. Valves, regulators, gages and instrumentation

g. Life support systems
h. Fire protections systems
i. Alarm systems
j. Personnel transfer provision
k. Electrical systems
l. Communication Systems
m. Wet-chamber systems
n. Facility operating systems including operating and maintenance procedures.

2. Design Technical Review

The applicant for certification submits, to the Material Certification Authority for review, appropriate documentation connected with the design of systems, sub-systems, components, and portions of the hyperbaric facility. This independent review is not intended to duplicate the design effort but to develop high degree of confidence in the design of the facility. The philosophy of this review may be summarized by NAVSHIPS PMS-381 approach "Show me how you got there".

The documentation should include at least the following:

a. The Program Cost Estimate which usually contains a brief description of the items mentioned in the material adequacy scope.

b. Design plans, specifications, and computations of the pressure resisting structure, the life support systems and all associated systems that have a bearing on the safety of the occupants or operators. The applicant must justify methods of design, and materials selected.

The depth to which analysis of the various systems is required depends upon the degree of confidence which may be established from the designer's capability and experience in hyperbaric facilities, the type of specifications which are incorporated in the contractual documents, and the method of analysis used. For example, during the review process of the pressure resisting structure a check will be made of how the American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section VIII, "Alternate Rules for Pressure Vessels, Division 2, 1968 Edition" is applied in the design process. Particular attention is given to the method used for areas of high stress concentrations and interconnected parts of the complex.

When the adequacy of the analysis of the systems, sub-systems, components, and portions of the facility has been demonstrated, the construction contractor receives authorization by the proper authority to proceed with procurement of various items.

3. Quality Evaluation and Control Program

A rigid "Quality Evaluation and Control Program" should be developed by the applicant for certification to assure the compatibility of the raw materials, warehousing, traceability of material, fabrication, and handling of the systems, sub-systems, components, and portions of the hyperbaric facility. Characteristics of materials which endanger the life of occupants in a chamber should be identified during the evaluation process. Procedures for quality control and inspection should be accurately defined and fully understood by personnel responsible for their execution.

4. Detailed Test Procedures

A test program should be submitted by the applicant to the Material Certification Authority which will demonstrate the adequacy of materials, systems, and equipment within the material adequacy scope. This program usually includes:

a. Tests of materials which are still in the development stage.

b. Tests of materials components, and portions of a hyperbaric-facility. For example, non-destructive tests and fabrication tolerances; tests at critical areas, the results of which will be compared with results obtained by stress analysis.

c. Tests of systems and subsystems. An example would be hydrostatic tests of the hyperbaric chamber and piping system, to confirm their design and operational characteristics.

5. Field Inspection

A group which consists of structural, mechanical, electrical, and life support engineers makes an inspection at the site to check for possible deficiencies in the various systems. These deficiencies may be divided into two categories:

a. Mandatory corrections necessary to avoid personnel injury or death and major damage to the facility.
b. Non-mandatory corrections recommended to upgrade the safety reliability, and operability of the facility.

6. Material Certification Authority Safety Review

The agency responsible for material certification of hyperbaric facilities forms a Board to review the documents collected by the Material Certification Project Engineer during the material certification process. The Board consists of nationally and internationally recognized experts in the special fields upon which the design and construction of the hyperbaric facility were based.

7. Issue of Material Certification

Upon completion of the safety review the Board recommends to the appropriate head of the Material Certification Authority that a material certification be issued. This material certification defines the conditions upon which the certification is valid and states the expiration date.

8. Recertification

The user applies for recertification upon expiration of the Material Certification period, or whenever the hyperbaric facility fails to maintain the safety requirement requisite to the issuance of the certificate.

E. CENTRIFUGAL AND CENTRIPETAL TYPE FORCES ACTING UPON THE MATERIAL CERTIFICATION FOR HYPERBARIC FACILITIES PROGRAM

Figure 5 is a graphic illustration of the various forces acting upon the material certification program. The centrifugal type forces tend to pull apart the program which occupies the center of rotation; centripetal type forces are required to maintain the equilibrium of the program.

It is mandatory that certripetal type forces exist in systems which are as complex as the ones connected with a hyperbaric facility. Therefore, it is considered, that justification of these forces is not necessary. Let us then examine the effects of the following centrifugal type forces:

a. Money
b. Time
c. Personnel; and
d. Material Certification Envelope

1. Money

The amount of money required for material certification of a hyperbaric facility depends upon the complexity of the various systems of the facility. Present experience indicates that approximately 10-20 percent of the total construction cost of a facility will be required for material certification. Of course, it is natural that some reluctance exists to pay for material certification. One rationale that might be offerred is that a sound set of plans and specifications which includes quality control and testing clauses is more than adequate to insure a safe facility without the material certification process. Another rationale that might be offerred is that the general statements contained in the material certification requirements probably will result in escalation of contract bidding prices. This can be minimized considerably by an original set of plans and specifications of good quality and specific in nature, not sprinkled with generalities.

It is considered, that an independent review of the hyperbaric facility will uncover possible weak areas and will increase the degree of confidence of the operating agency. The documentation necessary and the quality control during construction will result in a top grade product. The safety of the human lives involved must be insured.

2. Time

Another provocative issue is the possible stretch-out caused by the material certification process. It is recognized that time is of essence during the execution of a contract. Certain time obligations have to be fulfilled and deadlines have to be met. However, a well organized design and construction time schedule can incorporate the certification process without loss of valuable time.

3. Personnel

The quality of material certification depends upon the talent available for this effort. In many cases private consultants may be hired to resolve highly complicated problems uncovered during the material certification process. These contingencies cannot be contemplated and therefore, additional cost requirements for change orders are generated.

It is to be noted persons involved in material certification constitute a separate group and should not be involved in any phase of the design or construction effort.

4. Material Certification Envelope

The determination of the envelope which is directly connected with the safety of the occupants and operators of the hyperbaric facility is an indeterminate problem. There is a tendency to minimize the envelope in an effort to save money. The risks to be taken is a matter of sound judgement and should be negotiated between all parties involved during the preparation of the material certification scope.

Other contributory forces which may be included as by-products of the centrifugal forces mentioned above are:

a. Lack of confidence of the user of the hyperbaric facility in the competence and capabilities of personnel working in the material certification area, and

b. Unfavorable publicity which presents the certification effort as a "white elephant".

E. CONCLUSION

The main objective of this paper is to describe the main steps of an independent review for material safety. This review is imperative due to the high complexity of the systems involved and their immediate impact on human life.

The critical factors of money, time, personnel, and material certification envelope can be minimized by team effort among all interested parties beginning at the time the design of the hyperbaric facility begins. The final product of this team will be a hyperbaric facility with high degree of safety, reliability, operability, and maintainability.

Finally the confidence the operating agency has for a materially certified hyperbaric facility indirectly will produce high quality test results.

ACKNOWLEDGEMENTS

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It is appropriate to mention the name of Captain W. A. Walls, CEC, USN, Assistant Commander for Engineering and Design, NAVFAC, for his encouragement in writing this paper.

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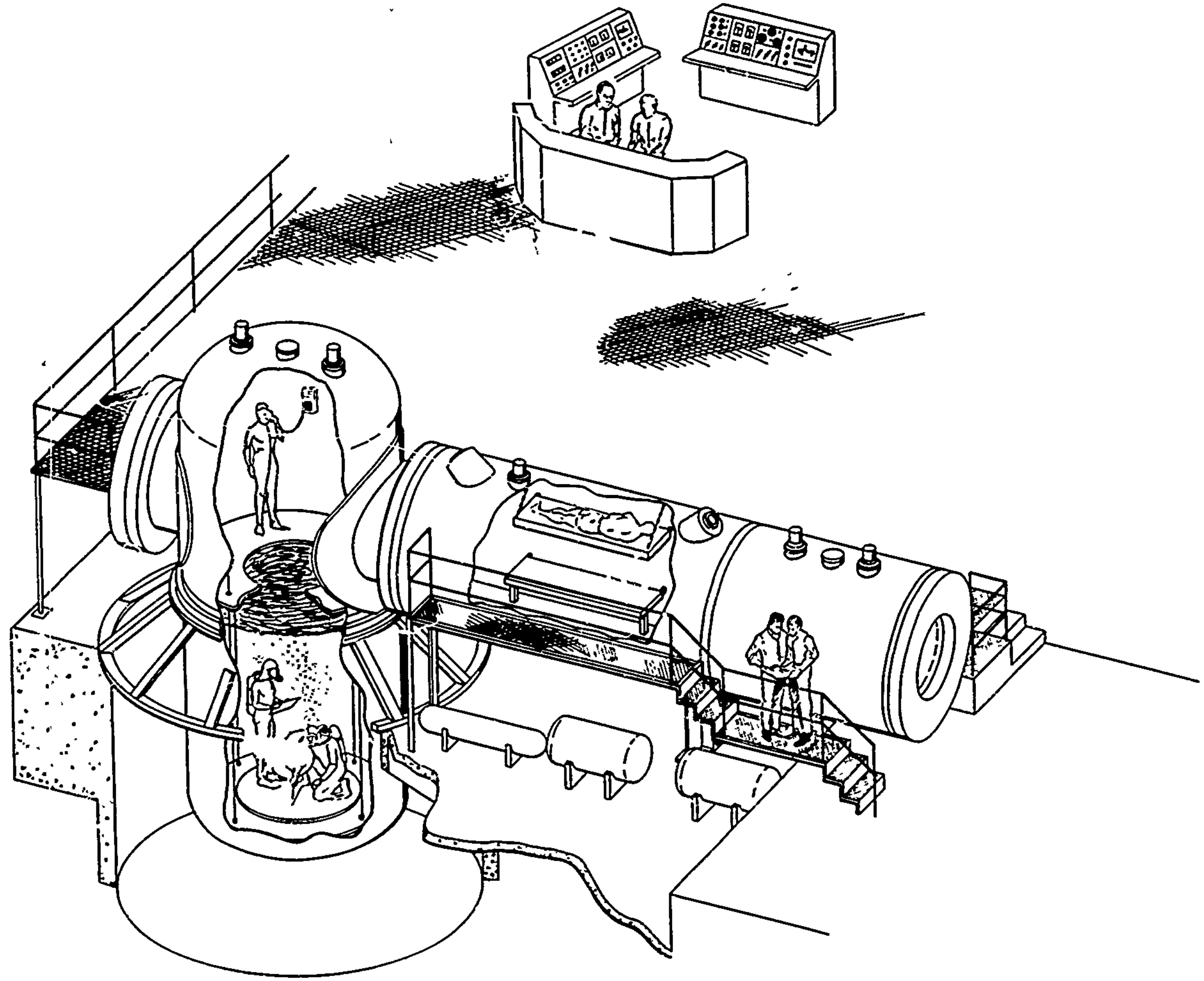


Fig. 1 Pressure Chambers, New London, Connecticut

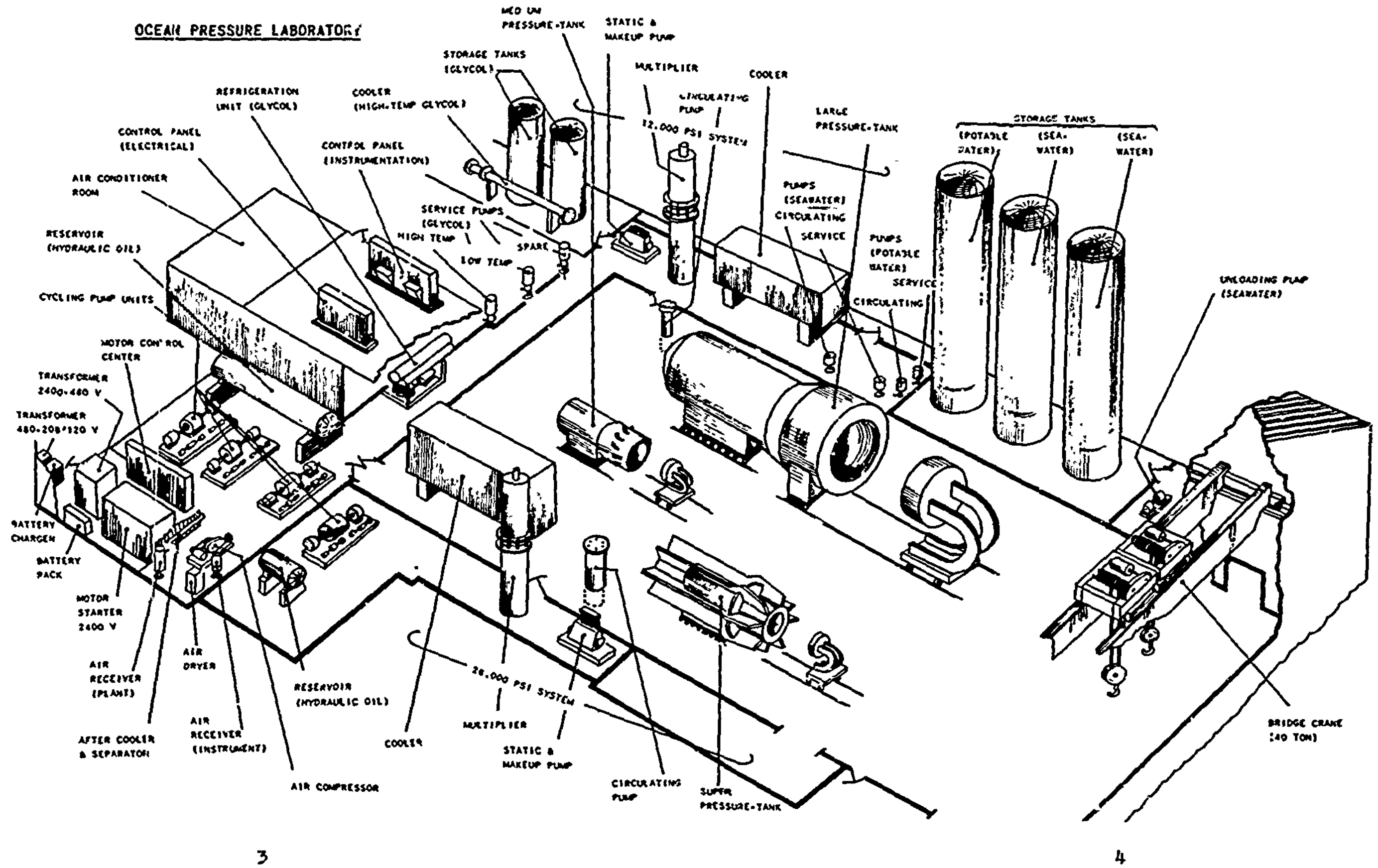


Fig. 2 Deep Submergence Test Chambers NSRDL/Annapolis, Md.

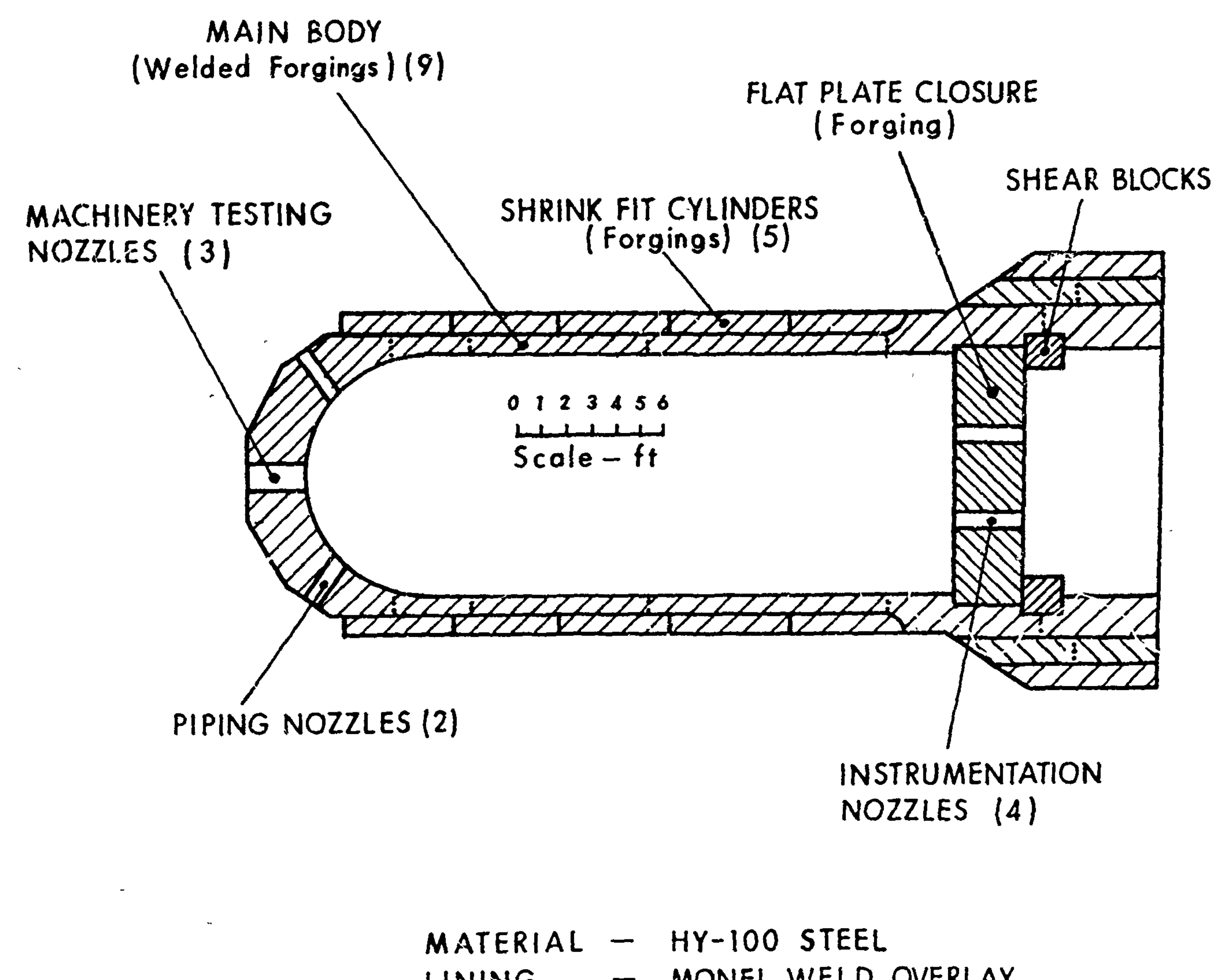


Fig. 2a Deep Submergence Test Chamber-A NSRDL/Annapolis, Md.

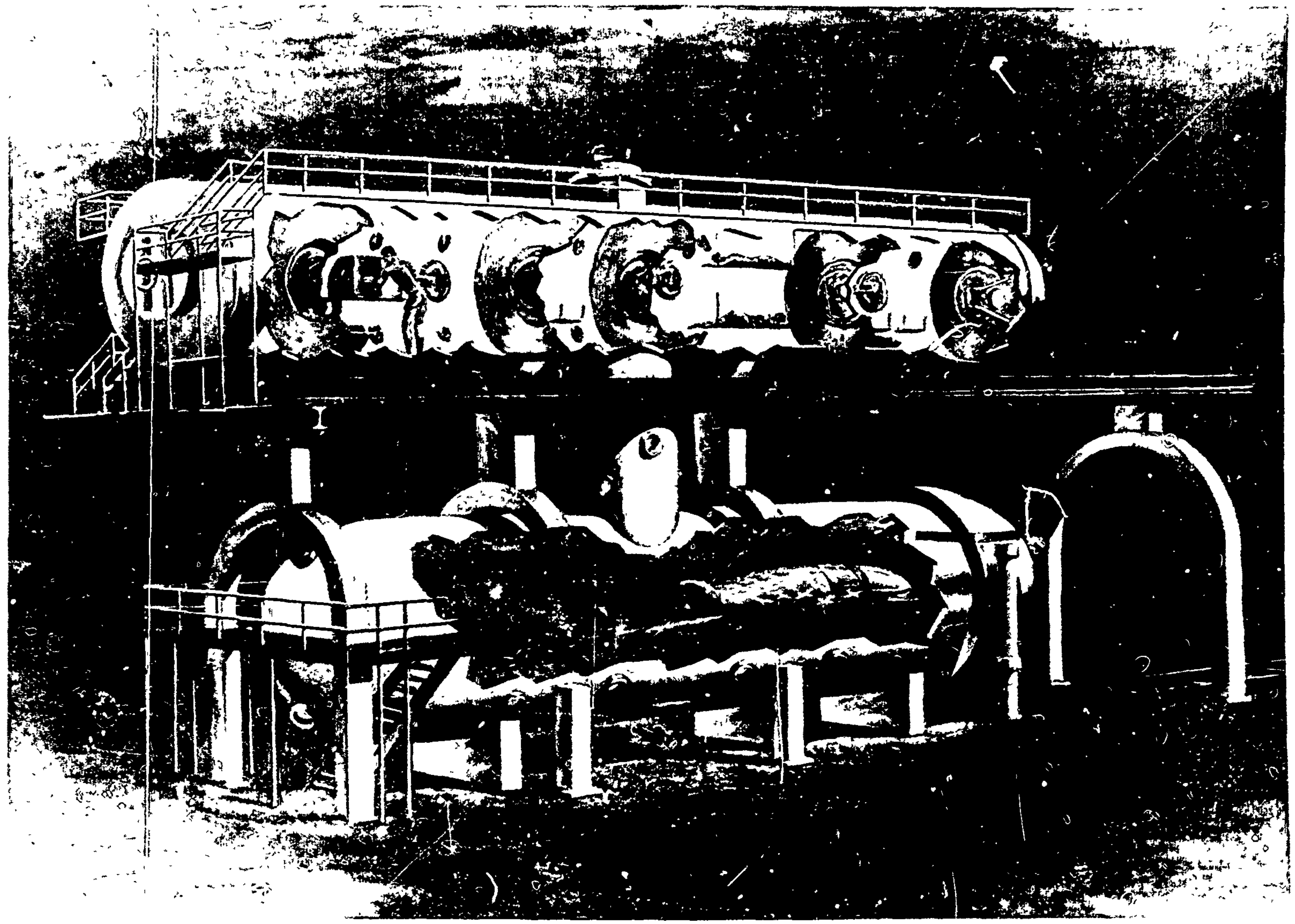


Fig. 3 Pressure Chambers, Panama City, Florida

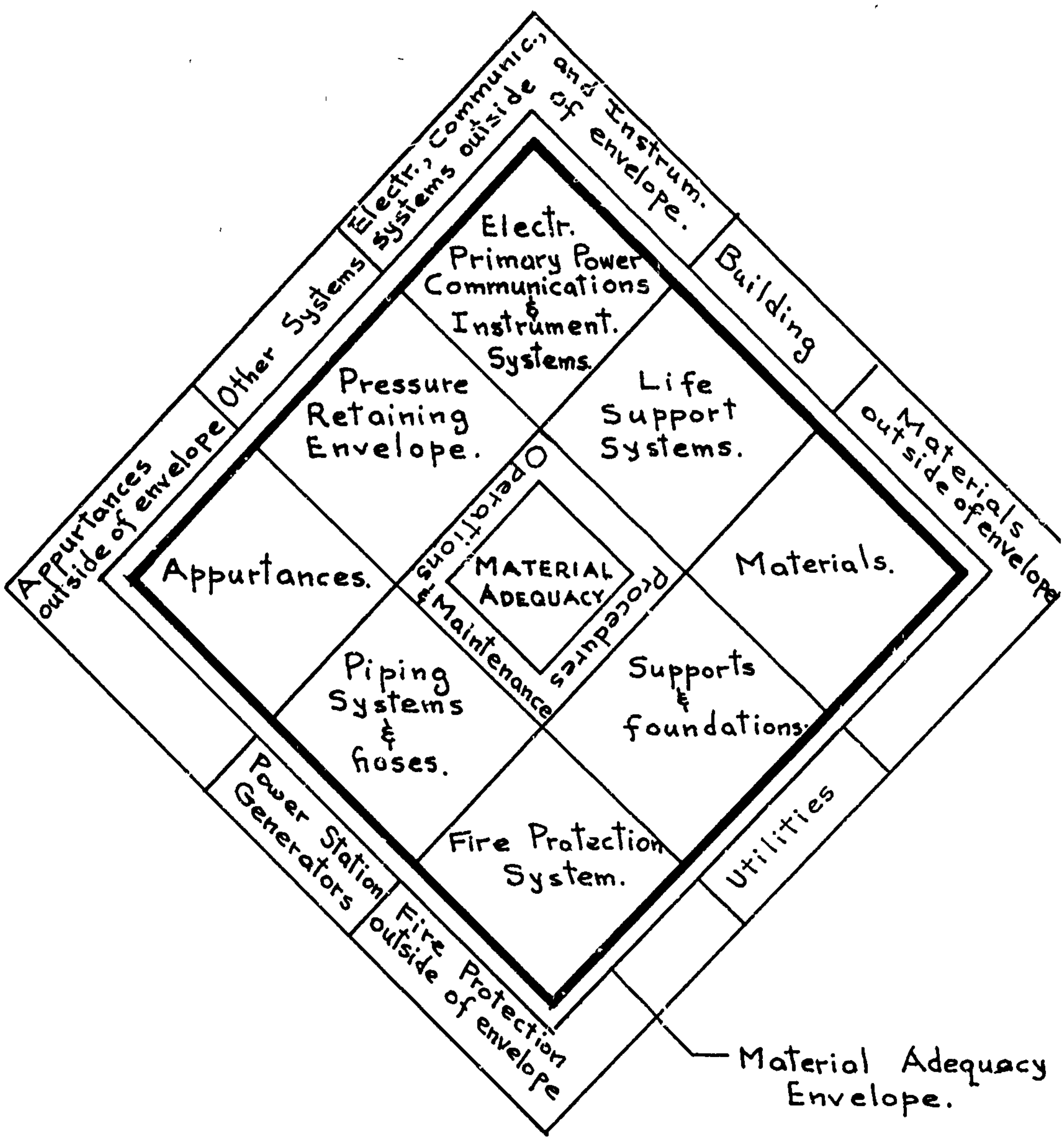


Fig. 4. Example of Material Adequacy Envelope

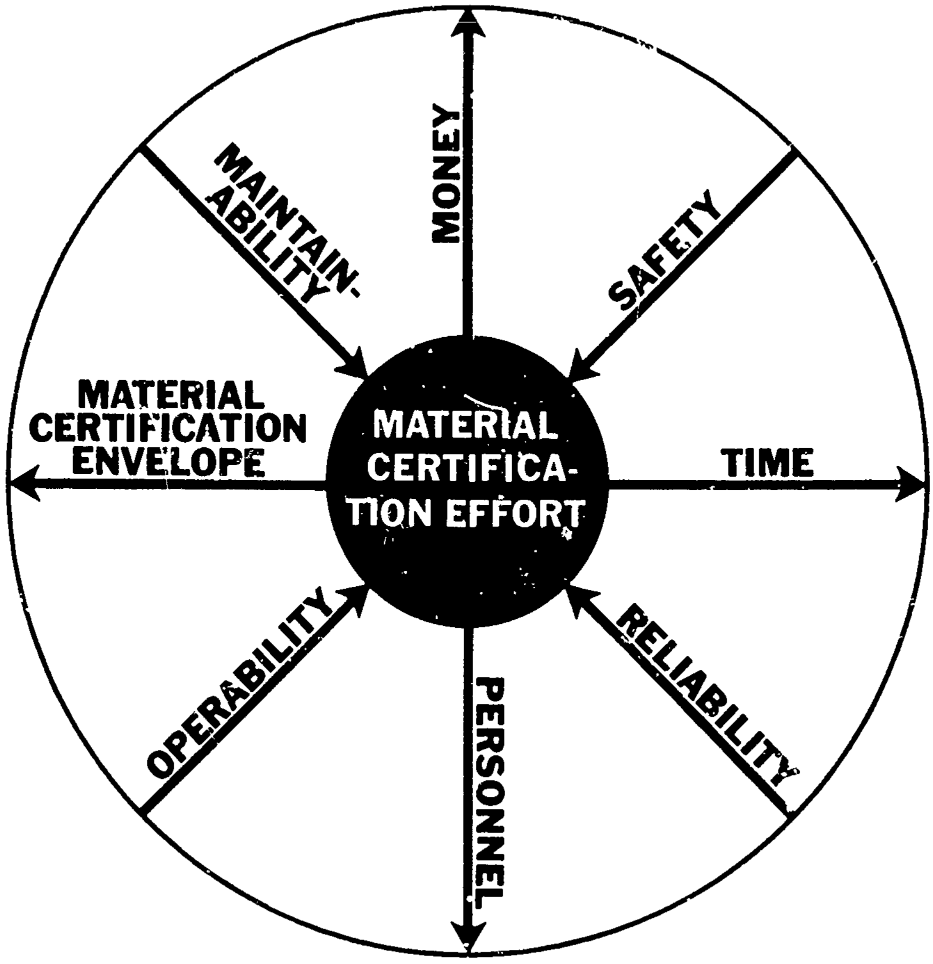
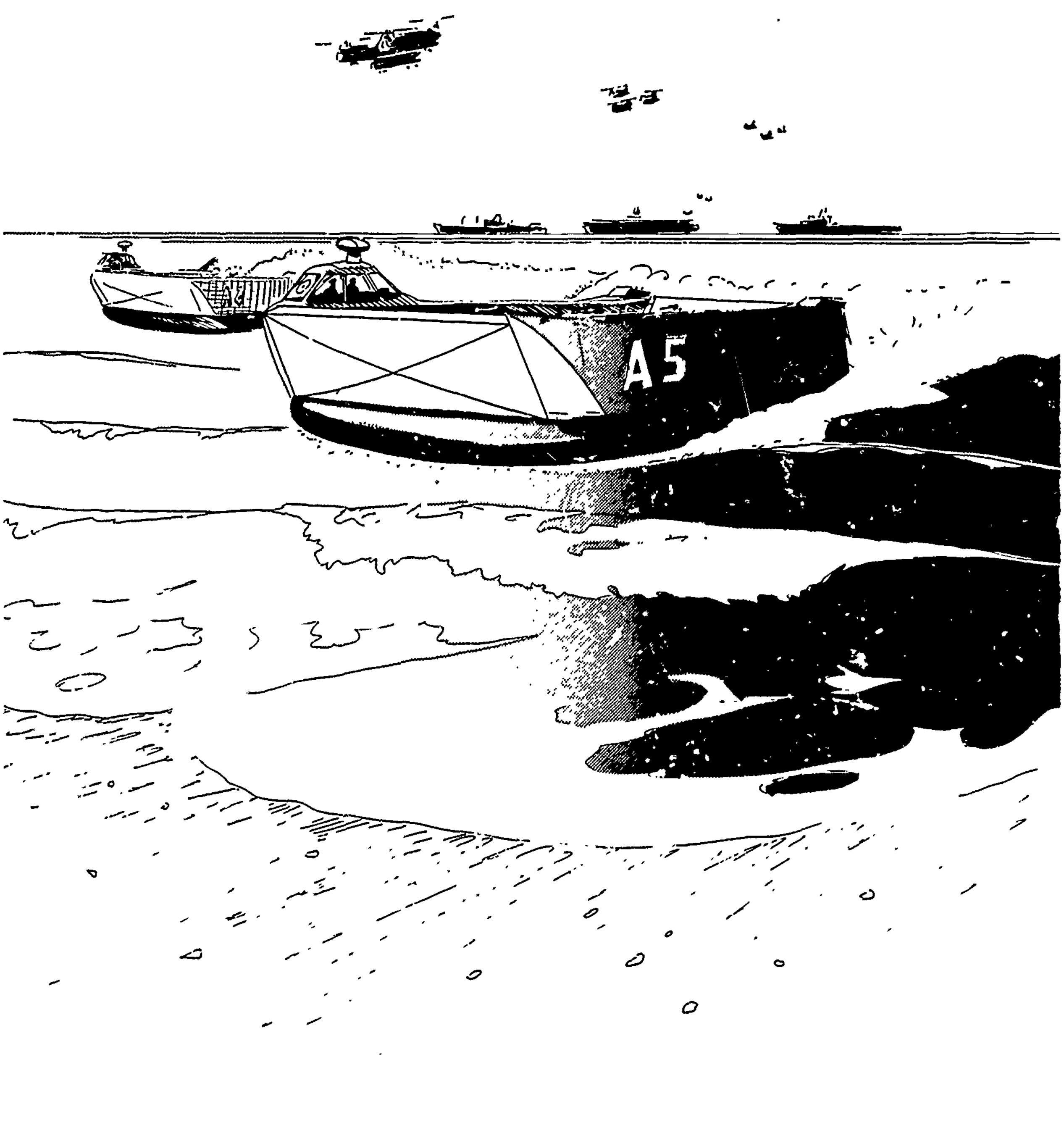


Fig.5.Centrifugal and Centripetal forces of Material Certification Effort.

Knowledge for Amphibious Warfare



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EFFECTIVE SURF DETERMINATION AND APPLICATION TO AMPHIBIOUS WARFARE; A REVIEW

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ABSTRACT

Current techniques for measuring surf data during Amphibious Operations are discussed. The reliability of surf measurements required for computation of effective surf, the criteria for determining the feasibility of utilizing various types of landing craft, is evaluated. Recommendations for more effective acquisition of surf data and possible employment of instrumentation are also set forth.

INTRODUCTION

One of the more crucial aspects of surface-borne Amphibious Operations results when landing craft traverse the surf zone. It is within this surf zone that the immense forces of breaking waves, longshore currents, and wind can broach or damage landing craft, thus placing the entire operation in jeopardy. Therefore, the Amphibious Task Force Commander (CATF) is greatly concerned about existing surf conditions and extremely interested in having the best available information about this zone, both current and forecasted conditions.

Numerous research projects and reports have dealt with surf problems and have provided environmental personnel with an abundance of useful information to assist in forecasting surf conditions. In 1967-68 Naval Weather Research Facility (NAVWEARSCHFAC) personnel conducted a preliminary survey of environmental effects upon Amphibious Operations, and published a qualitative resume of weather effects that has proved very useful in forecasting (1). Both Amphibious Force Fleet Commanders have published a basic instruction, The Joint Surf Manual, which sets forth procedures that are currently being utilized for surf forecasting and surf observations (2).

The importance of accurate information of surf conditions and the effects on Amphibious Operations is well recognized. Surf and beach conditions that are to be encountered are expressed as the "effective surf" height, which is a modification of significant breaker height. It is felt a review of techniques now in use for measuring desired parameters, evaluating the effects of inaccurate data in computing the effective surf, and discussing the need for research and development for accurate instrumentation is warrented. Therefore, this paper will deal with these specific topics.

SURF MEASUREMENTS

Computation of the effective surf requires collecting specific information on certain characteristics of the surf. These parameters are breaker period, breaker type, breaker angle, littoral current, wind direction and velocity, secondary wave heights, and significant breaker heights.

Many personnel resources such as Underwater Demolition Teams (UDT); Sea, Air and Land (SEAL) Teams; Marine Reconnaissance Teams; Beachmaster Units; Boat Group Commanders; and observers both ashore near the landing beach or afloat are all employed at various times to gather surf information. There exists a major problem in training qualified personnel with the wide selection of observers that may be called upon, and the lack of experience can often lead to unacceptable errors in measured parameters.

There is only a small amount of detailed information available formulating measuring techniques for each parameter. The most frequent observation tool is the "seaman's eye" or "an experienced hand". Just as in forecasting surf, measuring surf conditions is still more an art than a science (3). Information contained primarily within the Joint Surf Manual is being applied for training personnel who are employed for gathering surf data. Few refinements have been made in measuring techniques since 1945, and data is normally collected without the aid of instruments except for a stop watch or hand anemometer. It is realized however, that the ability to obtain "reliable" information,

"Superior numbers in parentheses refer to similarly numbered references at the end of this paper."

without instruments, has definite advantages.

Present methods in use for measuring the various parameters are as follows:

1. Significant breaker height is determined by observing one hundred successive breakers, then calculating the average of the highest one-third. The observer can also count the breakers that occur for a period of ten minutes and then calculate the average height. Breaker heights are measured by standing in the surf and using the body as a measuring device, using some reference point in the surf zone such as a rock, or taking an "experienced" guess. A measuring rod may be placed in the surf zone to give the observer a visual height scale. In another method the beach observer can raise or lower his eye level until the horizon is obscured by the surf, to get an idea of how far a wave is above the mean water level. An additional one-third is added to compensate for the portion of surf below mean-water level as well as parallax error (1). Although the methods are primitive, they are probably adequate for this application. These methods are not a reflection of the state of the art, but are the methods currently in use by the fleet. Significant breaker heights must be determined to the nearest half foot.

2. Breaker period is obtained by using a stop watch to record the time interval while observing the one hundred breakers and then calculating the average time to obtain the period. Values must be calculated to the nearest one half second. Since wave period is considered nearly constant, approximate values can be obtained by environmental forecasters aboard ship.

3. Breaker types are recorded as spilling, plunging, or surging. Personal experience is the only means of determining the breaker type present. Beach slope, which is also measured, assists in determining breaker types; however, winds near shore, tides, and currents from river mouths can change breaker types that would normally result from beach gradients.

4. Littoral current is observed by throwing an object, which will float, into the surf and pacing off the number of feet it drifts along the beach in one minute. The current speed must be calculated to the nearest tenth of a knot (each ten feet is equal to one-tenth knot of current). Actual measurements of these currents produced by all types of waves show a wide variability in speed, the variations being equal to the average speed for a number of measurements; thus the observations should be done several times and averaged (3). Nomograms have been developed which may be used for determining the longshore current when the breaker angle is known (Fig 1).

5. Breaker angle is observed by facing seaward and estimating the acute angle the breakers make with the beach. The angle must be measured to the nearest five degrees. A hand compass or protractor may help in determining the angle, but it is difficult to achieve the accuracy required with these devices. It is possible to compute the breaker angle by knowing the deep water wave length, the depth at which breaking takes place, and the angle the deep water waves make with the depth contour (Fig 2); thus giving an approximate value for the parameter. This parameter is perhaps the most difficult to observe (1).

6. Wind direction is observed in relation to the beach orientation. A compass or protractor may be used to assist in determining the angle. Wind speed is normally obtained from a hand anemometer.

EVALUATION

Once the observed values of surf characteristics are obtained, the effective surf is calculated to determine if conditions are favorable for using various types of landing craft (Table 1). It is readily apparent the range of values of maximum effective surf for the two extremes for landing craft, LCVP and LCU, is small (i.e. 6 ft to 9 ft). The largest contributing factor in effective surf computations is the significant wave height. A one foot error in determining this parameter is enough to effect the type of craft that can be operated safely.

Errors made in obtaining values of other parameters can require as much as four feet to be added onto the significant wave height (Table 2). The possibility could exist when effective surf calculations would indicate no craft should be operated, when in fact all but perhaps LCVP's could be used.

It is realized that "experience" and "seamanship" are extremely important and cannot be overlooked. However, the environmental forecaster must be able to provide the Commander with information that he can have confidence in and know his judgments are based on the most accurate resources.

SUMMARY AND RECOMMENDATIONS

Given precise data, in sufficient time, the CATF is more assured of success of the amphibious landing. If necessary, readjustments to H-Hour and scheduled landing waves can be made, and times can be selected when surf conditions would not hamper administrative offloading over the beach. Most important, known or forecasted high surf conditions will give warning and prevent loss of life or damage to equipment.

We all admit that the methodology and procedures that we now use for surf forecasting are not perfect.

* They were developed as long ago as World War II.
* Nevertheless--they are all we have. We should therefore utilize the best input data that we can obtain when employing these procedures.

This community should then continue to strive for two things:

* First of all--continue efforts to perfect improved surf forecasting procedures.
* Second--until such time as a breakthrough provides an improved forecasting procedure, we should improve our measuring techniques so that we will provide valid data as inputs to our current forecasting procedures. In particular, the three crucial measurements are:
    1. breaker heights
    2. breaker periods
    3. breaker angle

Therefore, I propose that:

Having instruments constantly in the surf zone recording present conditions would better indicate surf buildup from local and diurnal effects, and provide initial data so necessary for accurate forecasting. It is proposed that instruments be developed that would gather all necessary data now required for computing effective surf. It is required that the sensors be small and compact, easily positioned, and of rugged construction to withstand the large forces within the surf zone. The instruments should be capable of being positioned by UDT type personnel. A proposed measuring device is shown in Figure 3. Sensors for detecting breaker height, period, and angle are located on two inter-connecting cables which cover the surf zone (one cable on each extremity of the proposed landing beach). Additional sensors are also on the cables for measuring longshore currents. The two cable arrangement would permit the capability to measure breaker angle. The two cables are connected to a transmitter located inside a buoy which also contains a wind recording device. The transmitter would provide data to shipboard recorders where the information could be evaluated and used to calculate an accurate effective surf on a continuous basis.

ACKNOWLEDGEMENTS

I wish to express my appreciation to Dr. Norman H. Jasper for his assistance in preparing this manuscript and for providing guidance in preparation for the Seventh Oceanographic Symposium.

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TABLE 1

Maximum Surf Heights for Training Operations

CRAFT/VEHICLE	MAXIMUM BREAKER	MAXIMUM EFFECTIVE SURF (FT)
LCM-6	6	7
LCM-8	7	8
LCU	8	9
LCVP	5	6
LVTP 5	10	11
LVT(R)	6	7
DUKW	5	6
CAUSEWAY (3'X15')	7	8
Self Propelled Barge (Pontoon)	6	7
Warping Tug (Pontoon)	7	8

TABLE 2

EFFECTIVE SURF CALCULATION

SIGNIFICANT BREAKER HEIGHT - - - - - - - - - - - - - - - - - - - ____________

BREAKER PERIOD - ____________

Adjustment Value

Significant Breaker Height	1-3.9	+.5	0	0	0	-1
	4-5.9	+1	+.5	0	0	-1
	6-7.9	+1	+1	+.5	0	-1
	8-10	+1	+1	+1	0	-1
	Breaker Period	3-5	6-8	9-11	12-16	over 16

BREAKER TYPE - ____________

80-100% Spilling	-1
21- 69% Plunging	0
70-100% Plunging	+1

BREAKER ANGLE - ____________

4^{o}R to 4^{o}L	0
5^{o} to 9^{o} angle	+.5
over 9^{o} angle	+1

LONGSHORE CURRENT - ____________

0 to 0.9 knots	0
1.0 to 2.4 knots	+.5
2.5 to 3.9 knots	+1
over 3.9 knots	1/2 speed

WIND DIRECTION/SPEED - ____________

Wind Speed	0-10	0	0	+.5
	11-20	0	+.5	+1
	21-25	+.5	+1	+1.5
	26-30	+1	+1.5	+2
	31-35	+1.5	+2	+3
	36-40	+2	+3	+4
	Wind Direction Relative To Beach	60^{o}-90^{o}	30^{o}-60^{o}	00^{o}-30^{o}

EFFECTIVE SURF (TOTAL) - ____________(FT)

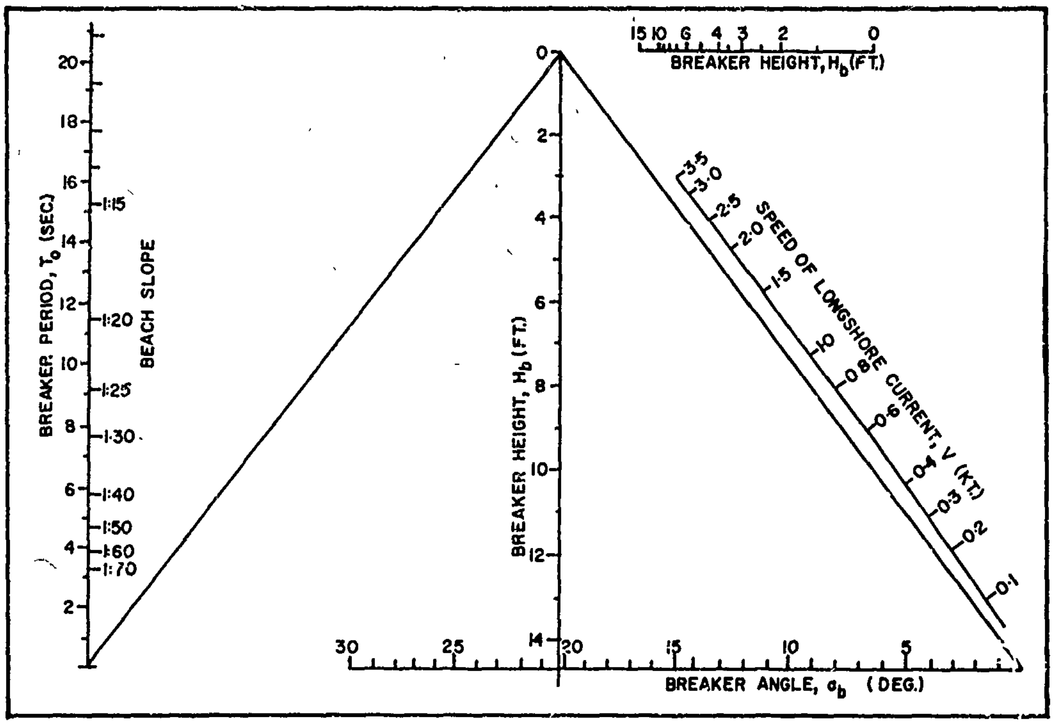

Figure 1
Nomogram for Determining the
Speed of the Longshore Current.

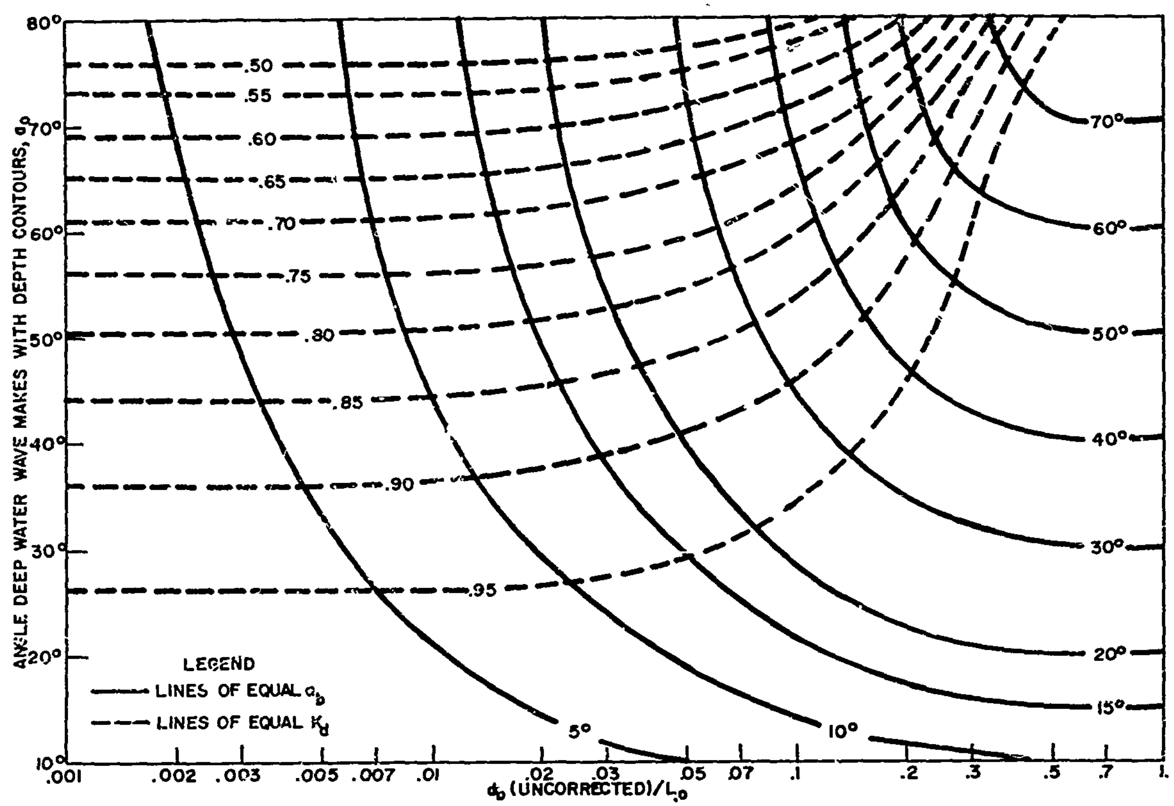

Figure 2
Graph for Determining the Coefficient of Refraction and the Breaker Angle.

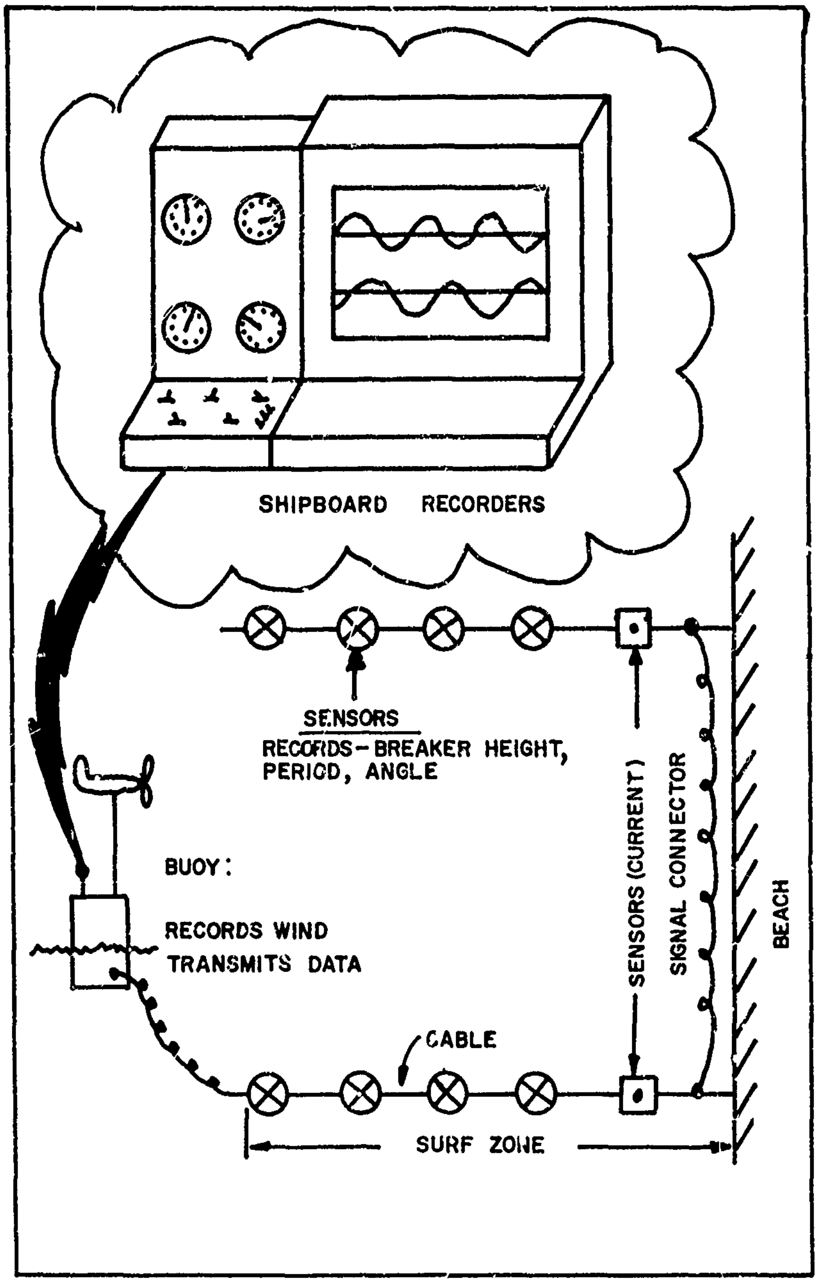

Figure 3
Proposed Measuring System for Surf Data.

RESEARCH FOR COASTAL ENVIRONMENTAL PREDICTION

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ABSTRACT

Development of a coastal environmental prediction system is dependent on the solution of a number of problems. Basic to such a development is the expansion of the data base to include the essential information on a worldwide scale. Another requirement is the improvement of the knowledge of environmental processes that control changes along coasts. Equally important is the design and establishment of data management procedures that will enable the rapid retrieval of data in forms that can be manipulated and interpolated in terms of coastal processes. Other problems are posed by the fact that different levels of command and decision-making require environmental predictions at different speeds of response and different degrees of detail. Despite the many problems involved, the outlook is favorable for improved prediction capability on a number of the aspects of coastal environments.

INTRODUCTION

The ability to predict accurately the environment along any coastal region in the world for any time period would be a great military asset. The process of developing this capability, however, has been relatively slow, beset with fundamental problems involving lack of knowledge and inadequacy of technology. To some extent, progress has been handicapped by the sporatic nature of the recognition given these problems. The objective of this paper is to address some of these problems and to discuss research efforts directed toward their solution.

Definitions

The term coastal environment encompasses all the marine, terrestrial, climatic and man-made elements found in the shore zone. The seaward and landward boundaries of the zone are not specifically delineated. Generally the zone is regarded as including the shallow water areas where bottom features are strongly influenced by wave action. Inland, the zone extends across tidal lowlands and may include broad, low-lying, coastal plains. The geographic elements or conditions of interest are all those having a bearing on military operations and equipment performance. Figure 1. notes some of these elements. In the beach zone, for example, the gradient is important, and so are sediment particle sizes, moisture content and pressure bearing strength; factors that affect a vehicle's ability to move. The entry on coastal climate covers an array of meteorological factors such as temperature and humidity regime, rainfall and wind characteristics, probabilities of blowing sand, dust and spray, and possible presence of snow and ice. The list in Figure 1. is only an abbreviation to indicate the wide scope of geographic conditions encompassed in the meaning of the term coastal environment.

Prediction is used in this paper to mean the determination and compilation of descriptions of environmental conditions to be encountered or most likely to exist at some projected future time in any selected part of the world. This forecasting will especially include statements on the conditions of the highly dynamic elements, such as coastal current velocity, breaker heights, and width of surf zone; features that are quite variable and closely linked to other conditions that are also undergoing change.

Naval Implications

The environment plays a significant role in most aspects of coastal operations. Figure 1. suggests some of these relationships between forms of naval warfare and elements of the environment. This role is cited in the Navy's General Operational Requirement No. 37 on Environmental Systems: (U) "In amphibious operations, the environment is a basic factor in the selection of landing area, beaches, D-day and H-hour. Amphibious craft are sensitive to wind, wave height and period, long-shore currents and beach gradients. Helicopters used in vertical assault are sensitive to wind speed, gustiness, turbulence, visibility and ceiling. Amphibious operations include a greater number of mission-function and environmental-factor impact points than any other naval operations."(1) The coastal environment may strongly influence, for example, the choice of weapons, the deployment of personnel and vehicles, methods used in reconnaissance and surveillance, and the conduct of search and rescue.

The military significance of the environment increases as equipment and operations become more complex. Advances in technology frequently mean a greater sensitivity to the environment. Increasingly, environmental information is needed in greater and greater detail. Generalities on average conditions are not sufficient either for the design of equipment or for decisions regarding its use in a particular locale. A vehicle of advanced design, for instance, can be very sensitive to loose surface materials such as dust and sand that can be sucked into motors that have high velocity, high volume air intake. Vehicles with limited climb rates are handicapped and even useless in the presence of high river channel banks, escarpments, trees lining a beach, and other abrupt changes in surface gradients. These two examples illustrate not only environmental dependence but also the fact that environmental information with a high degree of detail will be required.

COASTAL ENVIRONMENTAL DATA BASE

Available Data Sources

The core of forecasting, of course, is a body of data with records of sufficient length to cover major variations and minor fluctuations in the state of phenomena. Although factual information is by no means complete for all the world's coasts, or detailed and accurate enough to serve present and foreseen requirements, the cupboard is certainly not bare. A mine of summarized and interpreted data is available in the National Intelligence Surveys and similar reports. The National Oceanographic Data Center houses certain types of marine information. Libraries of technical reports, of maps and of aerial photography are also rich sources of particular kinds of coastal information. There is no question that these and other sources are very valuable, but using them is difficult, time consuming and costly. They are physically separated and scattered around the country. They contain information of uneven quality and coverage. For the most part, they are not in forms that are immediately or easily converted to computer storage.

Work is underway on a modest scale to convert some of these sources to forms for automatic data processing. In various stages of planning and development there are a number of systems intended to improve the handling of intelligence information, including some

Superior numbers in parentheses refer to similarly numbered references at the end of this paper.

environmental information. The Marine Corps, for example, is developing the Marine Air Ground Intelligence System (MAGIS) composed of several subsystems concerned with imagery processing and interpretation, storage and retrieval, intelligence analysis, tactical electronic reconnaissance processing and evaluation, and processing electronic warfare information.

There are other planned and on-going systems designed to speed the processing of intelligence information and certain kinds of data for mapping and charting. These, however, are not prediction systems. They do, nevertheless, offer sources of data that should be integrated or tapped for the data base of a prediction system.

A variety of oceanographic and meteorological factors are presently included in the Naval Weather Service Command prediction system. Computer programs have been developed to:

(1) Predict water levels in areas where tide and current data are very inaccurate because of wind conditions.

(2) Predict sea and swell conditions.

(3) Predict surf and breaker conditions provided the beach contours are known.

(4) Predict sound propagation based on known bottom types and depths combined with the chemical and physical characteristics of the water.

New Data Acquisition

Clearly, for these forecasts, considerable amount of basic information must be supplied to assure accuracy. For many places this basic information is lacking, or sparse, or out-of-date. While there are continual research efforts to develop means of bridging data gaps and identifying faulty information, there is also a constant need to foster the acquisition of new data. Research programs concerned with the dynamic processes of nearshore and beach areas, and with riverine and deltaic areas, are also valuable sources of new information, especially on areas and types of localities not found within the United States. Unfortunately, these sources have not been capitalized upon to the extent that their potential value would seem to warrant. Although at this stage of our knowledge of both coastal processes and data requirements for environmental prediction, it would be wrong to try to standardize all the observational efforts of basic scientists, better use could be made of the field measurements obtained by these scientists. The Navy, of course, calls on its own representatives outside this country to supply specific information; some is probably on environmental conditions. In the highly changing environment of the coastal zone, data sampling, especially on a one-time basis, poses fantastic problems of validation and reliability. Regrettably, very little research is concerned with sampling problems in coastal environments, with the effectiveness of spatial grids or other sampling distribution patterns to represent a field condition, or of the temporal frequencies of sample-taking or observations necessary to characterize properly a dynamic condition, or with the appropriate size of sample or length of measurement period. Improvements in knowledge of these aspects of sampling methods would provide guidance to naval and civilian scientists, both shortening the time needed for field observation and heightening the value of the results.

Increasingly, novel remote sensing techniques will be employed in the acquisition of new coastal environmental information. Many possibilities for the use of these instruments to acquire environmental data have been identified and reported on by study groups concerned with oceanography, geography and other earth sciences.[2][3] The potential of remote sensing is a large subject and will not be discussed further here. A number of research programs are underway to improve the Navy's ability to select the best sensor for the environmental conditions to be observed, and to extract and interpret information from sensor records. In the Geography Programs of the Office of Naval Research, the remote sensing effort pays special attention to identification of shoaling and breaking waves, nearshore water depth, shallow water bottom configuration, beach composition and moisture (ground water levels), and riverine properties. As is true of other programs, the ONR effort includes multispectral and single band sensors. Experiments include the acquisition of ground data, both to calibrate the sensors and to guide imagery interpretation. Special emphasis is being given in the ONR program to the study of the potentials of passive microwave sensors as coastal environmental data-gatherers. These sensors are particularly attractive because they offer all-weathe, day or night, nondetectable capability. A variety of frequencies (1.4, 4.99, 9.5, 13.4, 16.5, 37.0, and 94 GHz) is employed in the experiments to determine the most useful wavelengths per environmental property. Coupled with the use of these microwave frequencies are infrared sensors and conventional cameras focusing on the viewing field of the microwave radiometers. Other experimental research supported in the Navy and elsewhere involves the use of side-looking radar, of various film-filter combinations including the new minus-blue aerial color film devised by William Vary of the Naval Oceanographic Office, and of various image enhancing techniques such as the additive methods of E. F. Yost of Long Island University.

All the coastal remote sensing research promises important contributions to the solutions of problems of expanding the data base needed for coastal environmental prediction. It is possible to look forward to a time when remote sensors will be joined to data banks and information systems directly, possibly by-passing the intermediate steps for data extraction and conversion. There are, however, many problems yet to be solved before this stage is reached, or before image interpretation is an automated rather than a human activity.[4]

Expansion of the data base needed for predicting coastal environments is not simply a matter of willy-nilly gathering together every bit of information. A very serious question is raised concerning just what is needed; what are the significant factors of the environment and how much information about them is required in order to make an accurate forecast? These are thorny questions that are receiving altogether too little attention. If there are some aspects of the coastal environment that are more important than others, that affect more profoundly any or all coastal operations, then these should be given priority with regard both to being gleaned from existing data sources and to being acquired as new data in order to develop a working prediction system rapidly. That "if" is a large one, however, and needs to be verified. There is another view that the efforts to develop data bases should not omit any aspect because it is not possible to define exactly the future demands for environmental information. History of operational successes and failures can be cited to support both positions. The "totalist" argues that the difference in effort is small between getting all the information or only the supposedly significant data, that advances in ADP technology will make it possible to handle the many, many billion bits of information that will be generated, and that the risks of not having information when it is needed are too costly to ignore. The opposition points to the vastly increasing capability to acquire data, as from remote sensing from spacecraft, and the threat of overloading any information system. They note the tremendous difficulties in devising an information or data management system that can accommodate such quantities of data and still have a quick response time. The resolving of the problem of what the data base should include is urgent and fundamental to the development of a coastal environmental prediction system. This problem is almost untouched.

Later in this paper more will be said about data management for environmental prediction, but before we leave the topic of the data base something should be said about the problems of redundancy, verification, and maintenance. Redundancy, a constant hazard in data banks, is not easily overcome. When identical information has been stored it can usually be found with simple computer programming techniques. It is a much more difficult matter to recognize duplication when the same thing is said in several different ways. New methods need to be devised for locating this kind of redundancy and for checking the validity of data inputs. Better knowledge of coastal environmental conditions themselves may offer means of checking the accuracy of data, both new and stored. At a minimum, safeguards need to be built into the data base that will flag any data that appears to be anomolous so that the operator or user of the system will be alerted to run further checks on the data.

COASTAL ENVIRONMENTAL PROCESSES

In an area so full of motion and change as is the coastal zone, environmental prediction involves more than the extraction or retrieval of information about a place. It involves the projection of the effects of forces, such as moving water and air, on the sea state, bottom sediments, visibility and all the other aspects of the coastal environment. This requires the generation of specific knowledge of these affects and the forms and mechanisms they involve, and the injection of this knowledge into the manipulation of information from the data base. You recall that earlier a point was made that prediction must include statements on the projected conditions of highly changeable elements. These statements can only be made accurately when they are based on reliable knowledge of the coastal processes responsible for altering and modifying the shore. In this scientific area a variety of research is being conducted, not only under Navy auspices, but also by the Army, Environmental Science Services Administration, National Science Foundation and others. Of special interest are those studies concerned with the forms, magnitudes and variations of energy produced by waves along a beach and by running water in river and tidal channels, the interactions of these forces with sediments and the nature of the resulting changes. General relationships of these strand forces and features are known in varying degrees of exactness. Beach and nearshore slope, for example, is known to vary with changes in shoaling wave energy, breaker energy, swash velocity, sediment settling velocities in turbulent fluids, water viscosity and temperature, sediment sizes and shapes, and local weather conditions. The exact nature of these interrelations is not well known, nor are the mechanisms that bring about the changes fully understood. In the ONR Geography Programs special emphasis is placed on studies of these relationships: for example, on the changes that take place in wave characteristics as increasingly shoal water is encountered, on the distribution of breaking-wave characteristics, on the generation of longshore currents, and on the critical thresholds of energy required to move various sizes of sediments. From field data, energy models are being constructed to mathematically simulate shore processes. As these become refined and perfected, they will form useful vehicles for the translation of static coastal data into its dynamic form.

Other research on processes is concerned with understanding the relationships in deltaic, riverine and tidal-flats areas. As in the shore areas, moving water picks up and transports bottom sediments to create new bottom topographies that, in turn, change the flow characteristics of the water. These general relations are shown in Figure 2., a diagram prepared by the Coastal Studies Institute of Louisiana State University. Water surface ripple and wave forms are related to bottom sediment forms and flow velocities. A key factor in this whole problem of water vs. sediment movement is turbulence, and this is one of the most difficult things to measure in nature. Consider the extraordinary complexity of the turbulence and internal velocities in the breaking waves. Nor is the situation much simpler in rivers, such as the Mississippi shown in Figure 3. where the flow seems largely made up of eddies, up-welling boils and other forms of turbulence. Although the complexity of the problems of processes is enormous, progress toward understanding and quantifying these processes is steadily being made. The pace of progress is, in fact, increasing as better, more precise instruments become available to improve the measurement programs, and as more scientific and public interest is focused on the problems of the coastal zone.

Some kinds of coastal environmental processes, however, still suffer from lack of recognition and shortage of scientific manpower. In particular, reference is made to the climatic aspects of coasts. Little attention is being given to the important changes that take place in air flow as it passes across the land-sea boundary. Differences in roughness, available moisture, condensation nuclei, electrical and other conditions cause changes in many of the properties of the air, and these in turn may influence wave dimensions, run-up, transport of salt spray and sediments, and a host of other interlocked conditions. As a research field, coastal climatology or meteorology is neglected, a sad fact that will have a delaying affect on the development of environmental prediction systems unless corrective measures are soon taken.

On the whole, the effort on process studies, and the financial support available for this kind of research, are inadequate to maintain a rate of progress commensurate with the increasing urgency for the establishment of effective prediction systems. Almost every month another illustration comes to light evidencing the need for more rapid and flexible means of describing the environment at a particular place and a particular time. Although automation of the storage and retrieval of documents has hastened the search part of the compilation of needed coastal descriptions, the interpreter or analyst must then plow through these reams of papers to ferret out the data he wants. Document retrieval systems offer no opportunity to compare places or to search for particular coastal conditions. These manipulations can only be made in a system that contains the information content of documents, photographs, maps, charts, and the like, rather than the materials themselves. Creating information systems of this sort poses a number of data management problems.

DATA MANAGEMENT FOR ENVIRONMENTAL PREDICTION

The development of automated data bases needs to move forward cautiously because very high costs are involved in all ADP systems, and especially the costs in converting from one generation of computers to another generation. It is certainly necessary to look for areas of compatibility and commonality among data systems and to capitalize on any possibilities of combining systems. Whatever the designs for the data base may be, consideration should be given to the forms of information that may be generated by remote sensors. Remote sensor technological development, on the other hand, should be related to the data base systems and to the data requirements for prediction. In other words, the entire effort in developing the Navy's ability to forecast coastal environmental conditions should be tightly coordinated.

Information Transformation

In discussing the development of data bases, mention was made of various problems of finding and extracting information, of verifying and up-dating or purging data. Involved in this is the problem of transforming the extracted data into forms useable by the computer. This is especially difficult when the information is not in numeric form, but is qualitative. Much of the environmental information on hand is of this sort, and research is being conducted to find ways to convert qualitative to quantitative statements. This involves the formulation, adaptation, and testing of various analytical and descriptive techniques.

The incomplete nature of coastal information poses other management problems. Research is, therefore, experimenting with various statistical and other methodologies to overcome spotty and imprecise observations. Development of these methods may also provide means of testing and evaluating data reliability.

Information in the form of maps, charts and photographs is costly to transform to ADP format by present methods, that is, purely by manpower. Automated pattern recognition techniques, on the other hand, are far from perfected to the point where they can be applied to anything as complicated as a map. Much of what a person sees and interprets from these graphic data forms comes from shapes and relationships among patterns that suggest, more than document, certain information. The map or photo user, therefore, extracts more information from the document than it superficially contains because he brings to it other knowledge and experience. This is where the machine runs into difficulties. It can only recognize what is obvious. Even so, automation of certain aspects of data extraction from graphs will greatly speed the development of information systems.

Conversion of information may also require the use of special languages devised to aid in coding environmental information from graphic and other sources, in describing forms and patterns of geographic elements, in conveying fundamental concepts, and in formulating queries. There are some research efforts on special languages, but there is a lag in the development of standardized glossaries and terminologies for coastal environments. The names of objects, conditions, processes and concepts vary widely and are encumbered with ambiguous definitions that handicap communications. The military has generated a number of glossaries but the acceptance and utilization of these are limited. This difficulty will have to be overcome if a prediction system is to be broadly useful.

Data Compaction

Redundancy, already mentioned, is one of the data management problems that can overload a system. Beyond this, however, there is also a wastefulness that results from using many entrees to describe an environmental property when fewer may convey all needed information. The use of known, highly probable correlations can reduce the amount of information that needs to be stored. The research on coastal processes that is identifying dependence among variables and measuring interrelations among geographic properties offers opportunities to reduce the volume of stored data. Better understanding of the natural systems can lead to development of mathematical statements that describe these systems, statements that are economic of storage space.

Information Systems Development

Coastal environmental prediction must draw on more than an aggregate of facts. Data must be structured and organized in such ways that the system can respond with differing degrees of detail, as required by the decision-making level querying the system. Investigations need to be conducted on methods of data selection, filtering, summarizing and generalizing to portray accurately the coastal environment at various scales. Many users of the system may want the environmental information already interpreted for them in terms of its naval impact. For them, an information system should include "naval ecology," data on the interactions between environment and man-and-machines in discrete naval activities, and research is underway to define and measure these interactions.(5)

It is to be expected that predictions will be required, not only in different degrees of detail, but also with different speeds of response. Techniques need to be devised to enable the system to accommodate a range of response-time requirements without loss of accuracy. These and many other data management problems need solutions before a highly flexible, completely adequate environmental prediction system can be developed.

Output

The form in which the prediction is presented probably should be varied, depending on the user. A major difficulty in these times of highly complex and technical machines is that the information produced may be only partially understood by the average user. Much of the value may be lost because of the communication problem, a huge problem that has always vexed the military. An anecdote concerning the Royal Navy illustrates the problem. The episode "had to do with a time when the British Fleet sighted the French on the horizon. The admiral hoisted a signal, probably some spirited remark, such as "Engage the enemy and they are ours," whereupon to his dismay the fleet lowered its sails, broke out the small boats in a hurry and these rowed furiously toward the flagship, under the impression that the signal read, "Today is payday."" (6) Unfortunately in the military as elsewhere, communication problems persist. For environmental prediction, studies should be undertaken to determine the most effective methods of presenting the information.

CONCLUSIONS

The prospects are mixed concerning the timely development of a coastal environmental prediction system as an aid in planning and conduct of amphibious operations. There are ambitious plans and fragmented efforts concerning the organization of the data base. Knowledge of the coastal processes that govern changes in the environment is increasing, although perhaps not fast enough to satisfy users needs. For some characteristics, such as nearshore water circulation for which there is a fair body of theory, forecasting may be routine although subject to improved accuracy. For other conditions, such as the climatic ones, reliable forecasting may not be possible very soon. Predictions concerning the totality of the coastal environment and of its effect on particular weapons or operations seem to be off somewhere in the future. How soon this capability is developed depends upon the support given to research that seeks solution to problems of data acquisition, discrimination, transformation, compaction, filtering, manipulation and other problems. Coupled with these efforts must be continued search for the principles that govern coastal processes and interrelations of environmental elements. The greatest need would seem to be for a coordinated effort to build and expand a computer assisted data base, and to develop the essential information system.

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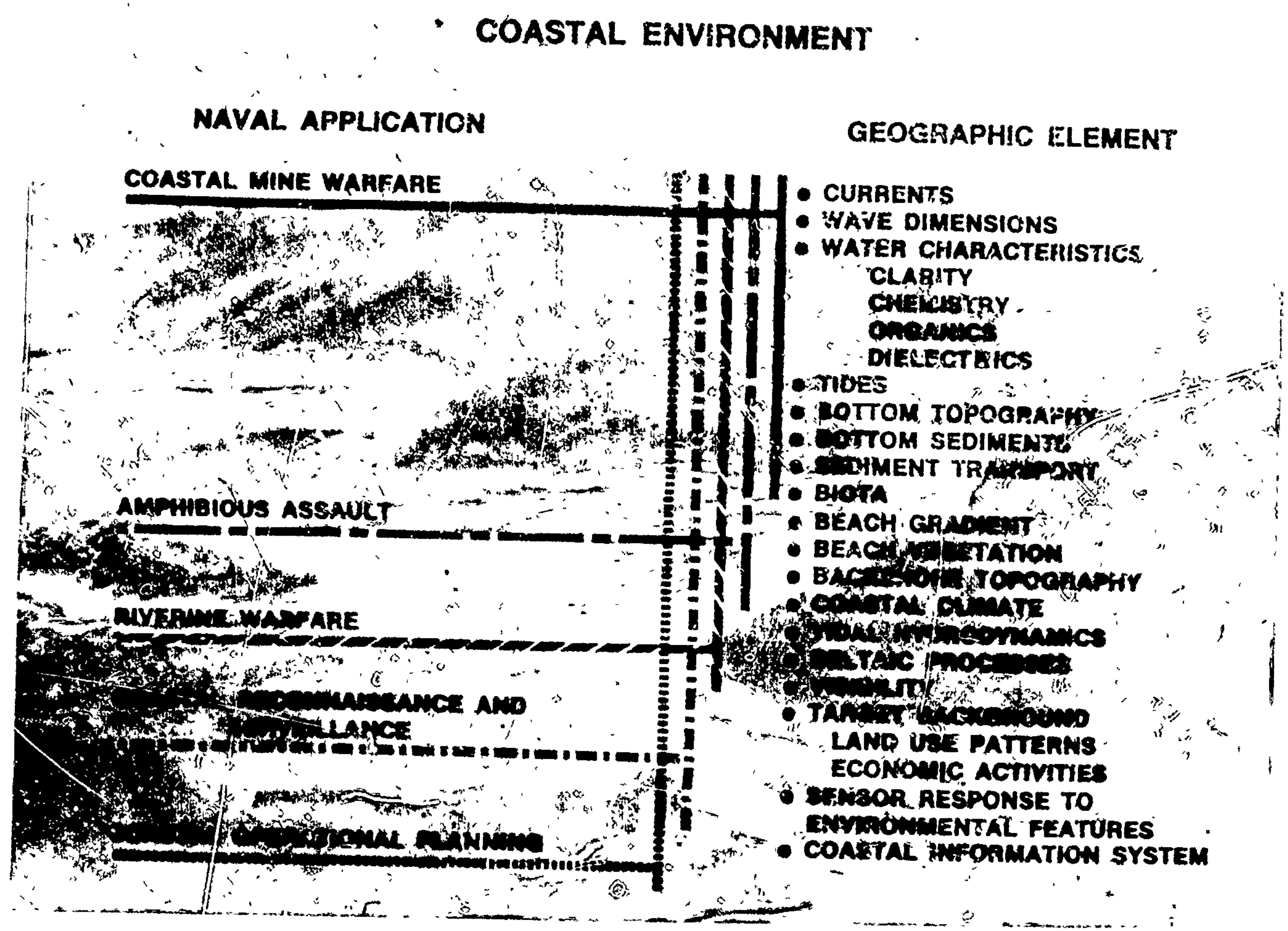

Figure 1. Relation of coastal environmental conditions to Naval warfare requirements.

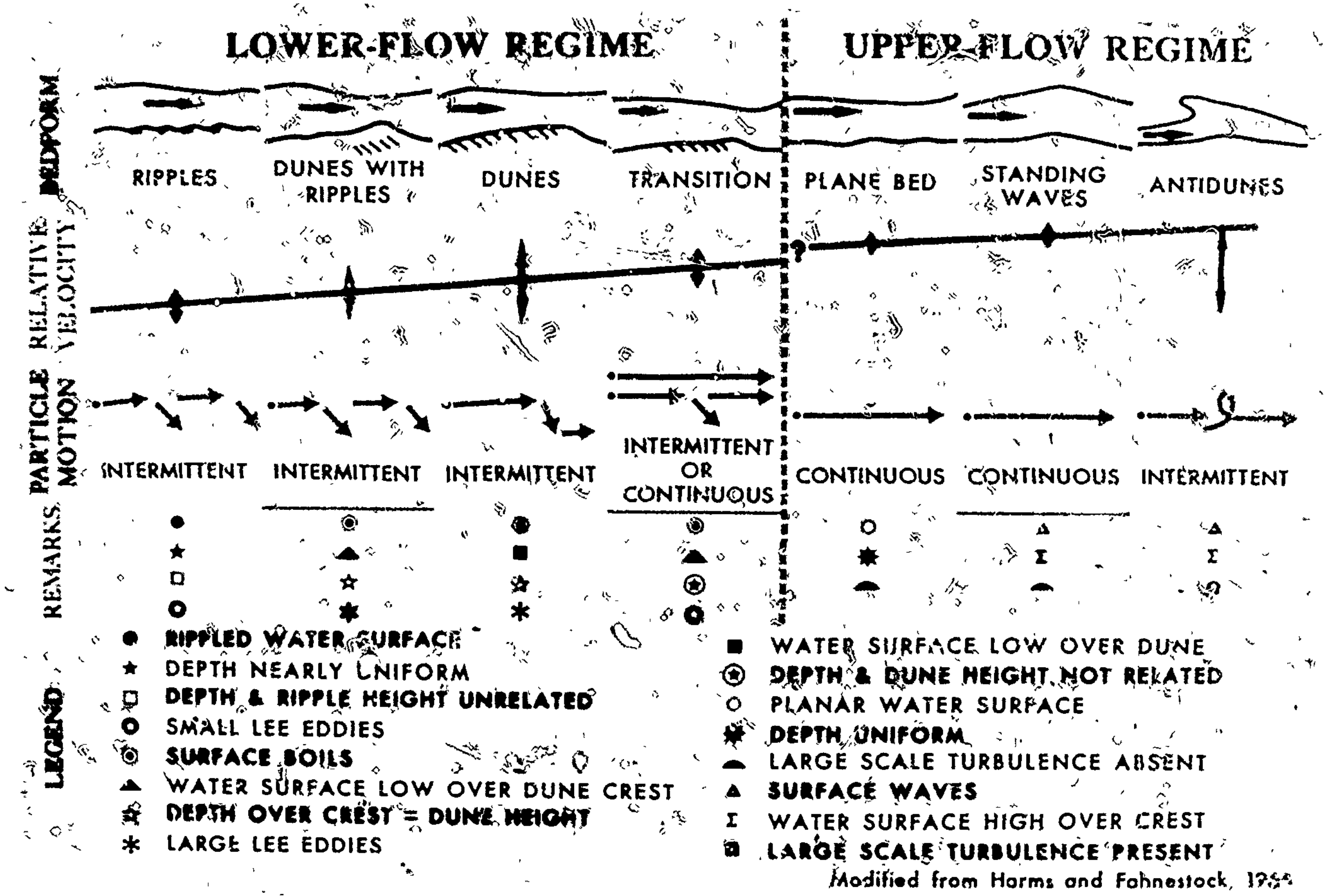

Figure 2. Changes in surface form of water, sediment and water movement, and bottom conditions accompanying increasing water flow velocities. (Courtesy Coastal Studies Institute, LSU).

Figure 3. Turbulent flow along lower Mississippi River, typical of large rivers. Dotted line A outlines the point bar; B is highly turbulent zone along edge of bar; C indicates eddies and vortices along the cutbank; and D is position of the deep-water channel. Boils are common in zones B, C and D. (Courtesy of Coastal Studies Institute, LSU).

A CONCEPT FOR ENVIRONMENTAL SUPPORT OF INSHORE WARFARE

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ABSTRACT

NIWEIMS or Navy Inshore Warfare Environmental Information Management System is a concept for providing environmental support of the inshore warfare missions of the Navy. The inshore or coastal areas of the oceans where environmental factors are most changeable and least understood become most constraining upon naval force operations. Navy Inshore Warfare mission areas in the broad sense include Mine Warfare, Inshore Undersea Warfare, Amphibious Assault, Swimmer-Diver Missions (EOD-UDT and salvage), Torpedo and Acoustic Countermeasures, Riverine Warfare and Harbor Defense.

The solution to environmental effect problems in the design and utilization of Navy shallow ocean warfare systems is conceived as a rapid buildup of information and knowledge available to all U. S. Navy forces concerned with operations in coastal waters. Modern information management and computer technology should be brought into use in order to reduce the time required to gain more thorough knowledge of the environment where Navy inshore warfare forces must operate. This understanding of the marine environment must permeate not only to the operating forces, oceanographers, geophysicists, acoustic and electromagnetic physicists but to others involved with developing naval equipment and providing technical support.

To achieve improved understanding and considerations of the environment an environmental information system is recommended. A five-year advanced development process is proposed to design, analyze, to build, test, prove and evaluate the system. System products will be responsive to both weapon system design requirements and support of operational forces needs. The products will take many forms, from environmental data in support of systems tests to prediction briefs of environmental effects on a weapon system operation in foreign coastal waters. This system will develop in parallel with other associated systems or subsystems over the next several years, e.g., OPDATS system. It also will develop alongside a massive buildup of coastal marine environmental data as proposed by the President's Council on Oceanography and Marine Resources. The basic or prototype system will be developed in five years at an estimated cost of $9,760,000 and utilizing 180 man-years of effort. The development of the optimum or complete system will take ten years.

INTRODUCTION

There is a deficiency of technical information pertaining to the variable natural environmental conditions in the shallow water areas of the world oceans which hampers the effective development of a suitable Inshore Warfare program within the Navy. This deficiency particularly affects testing and evaluation of surveillance sensors and shallow-water weapon systems and hampers the development of tactics and operational contingency planning for specific shallow ocean areas (see Figure 1). Neither shallow water environmental data nor adequate models for predictions exist in quantity or quality for the Fleet or Navy laboratories engaged in R&D of Inshore Warfare Systems. Many phases of naval operations including surveillance, gunnery, amphibious operations, mines and mine countermeasures are dependent upon meteorologic, geographic and oceanographic information for planning and performance. As military technology advances and becomes more complex, military operations and systems tend to become more sensitive to natural environment. Nowhere is there a central Inshore Warfare environmental information center to supply the needs of the Fleet or the Navy laboratories.

Many of the deficiencies can be eliminated by the establishment of a modern environmental information management system which will provide for an easy flow of a variety of meteorological, oceanographic, geological, geophysical, and geographic information.

This report describes a system designed to respond directly to the stated intent, purpose, and concept of requirements of GOR-37 (Environmental Systems) from the restrictive point-of-view of shallow water or coastal environmental needs of the Fleet as unspecified, but complimentary to deep ocean requirements. It also responds to requirements of GOR-24, Underseas Surveillance Systems; GOR-26, Mine Countermeasures; GOR-38, Special Warfare; GOR-42, Ocean Sciences (draft); and GOR-46, Ship Support, in that it considers the need for environmental information to develop and operate systems related to these requirements. It also supports GOR-14, Amphibious Assault; GOR-27, ASW Ancillary Support; and GOR-31, Command and Control[1 - 9].

In part, the requirements for a NIWEIMS or Navy Inshore Warfare Environmental Information Management System, have been based upon Fleet exercise reports[10] and informal field reports from Vietnam Laboratory Assistance Program (VLAP) activities in Vietnam. Environmental information and predicted environmental parameter effects would be particularly valuable to guide strategic and tactical planners in the areas cited above.

The NIWEIM System would have a five-year model advanced development period to establish technical feasibility, military usefulness, and cost effectiveness. The development of the System will be centered around building a digital information file of marine environmental data, and a simulation and computation software file of the effects of environmental parameters upon weapons and sensors.

Environment information will enter the System through an acquisition/data exchange program from military and civilian environmental data centers which would provide digitized shallow-water environmental data on a donation, trade, or purchase basis (Figure 2).

Products of the System would take many forms including raw data, data analyses, bibliographs, annotated technical publications, environmental guides for operational instructions, graphs and charts, environmental atlases, reference information and, where feasible, predictions of the state-of-the-art environmental effects on specified weapon systems. For example, most urgent and useful application is prediction of the environment in relation to its effect on operational performance, i.e., sea, breaker and surf predictions prior to amphibious assault, sonar conditions for IUW applications, and prediction of the occurrence of low frequency pressure fluctuations near the seabed for pressure influence minesweeping.

THESIS AND PARTITION

With this introduction then a broad band system for dealing with Navy environmental problems will be outlined and described below and justified using a few examples of applications for weapon systems. In keeping with the theme of this session, at least one such example should relate to the amphibious assault mission.

The U. S. Navy is one of the most demanding consumers for marine environmental information pertaining to the coastal zone. All Navy surface ships and subsurface boats must traverse the coastal zones to arrive at a port or depart to the open seas. Many types of Navy activities, including amphibious assault, inshore undersea warfare and riverine warfare, are critically sensitive to the nearshore and narrow waters environment. The need for increased and extensive environmental world-wide efforts was most clearly stated by the Oceanographer of the Navy in June of 1968[11] when he said "The nearshore and narrow waters environment is the most changeable area of the earth's surface. This is where air, the sea, the ocean bottom, the shore and river waters meet and mix.

"We cannot predict it accurately
We do not understand it completely
We cannot sample it adequately
and we cannot define it concisely."

Superior numbers in parentheses refer to References.

Although significant progress has been made since June of 1968, and notably in the riverine area, much remains to be accomplished.

DEFINITIONS

Inshore Warfare Environment

Terms such as inshore, coastal, nearshore, shallow water, narrow waters are often used interchangeably and may mean different things to different people. For example, just how deep may "shallow water" get? For the purpose of this report "Inshore Warfare Environment" is defined to be the predominately marine (salt water) environment extending from the 100-fathom depth curve to the beach, including contiguous estuaries, lagoons, and river distributaries where the Navy employs men, ships and weapon systems for mine warfare, amphibious assault, reconnaissance, surveillance, inshore undersea warfare, underwater demolition, explosive ordnance disposal and riverine warfare.

Interactions among the several warfare operations listed and the inshore marine environment result in problems at all levels of endeavor, from planning to landing (Figure 3).

Shallow water oceanography is an interdisciplinary mix. To solve inshore warfare systems problems where interaction between system and environment is a limiting factor and interaction often degrades system performance, a careful consideration of the total of environmental effects is recommended. Figure 4 illustrates in one conceptual form the mixture of disciplines, environmental effects and hardware or operational problem areas one may encounter.

Consider a specific example. The Environmental Effects on Sonar Performance (for almost any detection application whether a mine case, swimmer or submarine) show the broad spectrum of equipment performance against parameters such as water column, surface interface, seabed, and other effects (Figure 5).

The specific environmental effects illustrated by this figure are familiar to most everyone working in the sonar area. The number of parameters, which one might consider to solve environmental effect problems (e.g., the SONAR problem) could very quickly become overwhelming. A Coast Guard oceanographic buoy study listed over 100 oceanographic parameters of interest[12]. However, the environmental parameters which appear to be of most direct concern in inshore warfare are:

1. Meteorological. Surface winds, air temperature, atmospheric visibility, cloud cover, precipitation intensity, humidity.

2. Water Motion. Tides, sea state, waves and swell, surf, current profile, pressure fluctuations, seiches, circulation, flushing, stratification, diffusion.

3. Water column structure or profile. Temperature, salinity, density, sound velocity, electrical conductivity, particulates, transparency, bioluminescence, ambient noise.

4. Hazards to navigation. Restrictions to waterways, overhead clearances, (obstructions).

5. Bottom characteristics. Depth, topography (roughness), sediment properties, strengths, obstructions, vegetation, magnetics, reflection coefficients.

These are explained in terms of desired accuracy and a detailed description is presented in[13].

Information Management

The management of information has tried the soul of man since he first learned how to record his behavior. One of man's first attempts to systematically manage information must have been a library. The problem of effective information management is not less difficult today than it was when the famous library was founded at Alexandria, the Greek center and naval base in Egypt in about 250 B.C. Although we now are blessed with the high speed electronic computer, automatic graphing devices, video and photographic imagery, basic principles for getting at information have not changed much. They may be structured or ordered differently for different applications or by different people. One such set of six basic principles for retrieval of information using a high speed computer is listed by Holm in his very readable treatise on "How to Manage Your Information."[14]. They are

1. Balance input and output effort

2. Evaluate single entry and multiple entry files

3. Describe items fully

4. Control the vocabulary

5. Know the subject

6. Select proper storage.

A very few definitions are in the order next from Holm again.

Data

Data are numeric or quantitative notations. Data concepts are mutually exclusive and are easily manipulated by machine. A major machine function is the operation it performs on numbers and symbols (alphanumerics).

Information

Information is knowledge concerned principally with qualitative concepts or ideas. Information concepts are not mutually exclusive, the concepts interact and overlap. Information may include data or quantitative products, but is not as easily manipulated by machines as data.

Items

Items are records, e.g., reports, abstracts, articles, catalogs, books and pictures.

Terms

Terms are used to represent concepts. In different systems they may be called descriptors, key words, uniterms or subject headings. Terms are stored as references to information. There is much talk about information retrieval, but most often we mean and do reference or item retrieval.

Information Management

Information management (from Webster) is defined to be the judicious use of means to conduct and control the communication of knowledge or intelligence.

THE NIWEIM SYSTEM CONCEPT

To meet the Navy's increasing demands for technical information on the coastal and shallow water areas of the world a Navy Inshore Warfare Environmental Information Management System (NIWEIMS) is suggested. The development of such a system centers around the building of a digital information file of marine environmental data, and a simulation and/or computation software file of environmental effects upon inshore warfare sensors and weapon systems. The NIWEIM System would have a five-year model advanced development period during which the technical feasibility, military usefulness, and financial acceptability of the systems concept is established. The model of an ultimate system would be fashioned, tested, and proven during the advanced development stage.

DESCRIPTION

Figure 6 shows a block diagram of the NIWEIMS concept. The core of the model system will be a digital computer center which will produce several products. The computer system must extract and analyze information from the various subsystem data banks by means of the system software or information retrieval subsystems. The subsystem data banks may be located at different Navy Laboratories or offices. They must interface with the central data bank or system and/or with each other. The system does not start from input zero because there are marine data of coastal zone areas available at a number of sources in the military establishment and from civilian centers, e.g., NAVOCEANO, NODC, ESSA, U. S. Coast Guard, the several Intelligence Agencies, and University coastal laboratories.

System design (Figure 6) is an early input into the system development and must be adhered to during the entire five-year model development phase. The heart of the digital computer center must be at least a third generation machine having a time-sharing mode capable of storage of a massive amount of data, rapid access, retrieval and the timely creation of products.

The data acquisition and data exchange blocks depict a continual input of environmental data during the System development. The volume of potential usable raw observational data could exceed 1×10^{11} data digits annually; it will be vital, therefore, for the successful operation of the System that careful extraction and selection of environmental variables and geographical areas be made. Data should be acquired both in time and spatial dimensions for seasonal monthly and diurnal effects for only those environmental parameters of interest.

NIWEIMS must provide for frequent data exchanges and updating of the subsystem data banks. Although one NIWEIMS facility will be the principal file builder and master archivist, several other Inshore Warfare support facilities, such as Command and Control centers, may also gather, process, and update shallow-water environmental data. A free and systematic exchange of file information, raw data, and retrieval procedures, will no doubt enhance and expedite the total NIWEIM System.

The products of the System will include raw environmental data; analyses of data, environmental predictions; annotated technical publications direct or indirect from the computers; environmental guides for operational instructions, condensed or extracted for Fleet or special user needs for seasonal and area situations; environmental graphs and charts of types and designs other than navigational or meteorological, and environmental atlases of varying types. An important product goal of the System will be the environmental predictions and forecasts. These prediction products will increase as the state-of-the-art and our knowledge of the shallow water environment increases.

The subsystems data banks would be particularly related to the environmental data bank and System operations. The output of specific environmental data and products will be influenced by the amount and type of environmental data in the central data bank, at the time of interaction. The amount of automation of the subsystem data banks and the type of inquiries that the subsystems levy upon the main system will influence and regulate growth of the System.

Figure 7 is a block diagram of the NIWEIMS as presently envisioned at the end of the five-year model development period. Environmental data would enter the system through an acquisition/data exchange program. Environmental data centers (Figure 8), such as the National Oceanographic Data Center, NAVOCEANO, and Fleet Numerical Weather Central, would contribute digitized marine data on a purchase, trade, or donation basis. The data must be in computer acceptable format when entering the System and, where possible, should be reduced to an extracted format according to the NIWEIMS data bank specifications. Environmental data acquisition and updating of the files must be a continuous effort.

After environmental data are acquired, in parameter groupings or by geographical areas, they enter Data Bank No. 1. The data bank initially may include only raw marine observational data in shallow and coastal waters, but the System must be capable of adding statistics and data analyses to the files for the environmental elements and geographic areas of special interest.

At the center of the block diagram, Systems Operations, is where analyses, computational and comparative functions in response to queries from the users are performed (Figure 7). Three major functions of Systems Operations are the computational mix and solution of environmental effects upon associated system weaponry and sensors; the evaluation of Inshore Warfare system effectiveness in the marine environment (actual or simulated), and the multiple operations analysis tasks where sophisticated data manipulation is essential.

Systems Operations cannot function properly without direct input and feedback from the block of functions labeled Software, Technology, Research. Software includes the computer programming and systems analysis tasks required in Systems Operation to maintain system improvement. Technology includes the procedural disciplines of operating, training and updating techniques within a modern information management system. Research includes a large assortment of improved technological advances that have resulted from university, defense-industry, or Navy laboratory research and development. The research support provided by the National Science Foundation and the Office of Naval Research in shallow water and coastal zone environmental problems will contribute to and in a sense regulate the future growth and effectiveness of a NIWEIM System to provide prediction products. The research function or subsystem is described in greater detail below.

At the base of the functional diagram are blocks covering Data Banks No. 2 through 8. These show the information files that will be developed, and accessible or attached to NIWEIMS. The subsystem data banks will include the essential engineering or operational information on the situations and manner in which equipment and operations are affected or constrained by the marine environment. The information computed by System Operations also should be fed back to the data banks for their updating (Figure 7).

Successful interaction of the subsystem data banks with System Operations requires functional software programs and format standardization. Careful design of this interface in the early stages of model development will minimize subsequent operating problems.

At the end of the fifth year of development, the Model System should be supporting several of the subsystem data banks.

A model NIWEIM System of a concentrated technical subject is proposed as the basic system. Within five years an effective model information management system can be developed, although a model system will not be able to answer nor anticipate all technical questions demanded of it.

The five-year development period would create a solid base for user/supplier relationships and for training people to run the System.

The System could become a subsystem of a larger inshore warfare or coastal waters information management system after five years.

System Operational Criteria

During the five-year development of a model NIWEIM System, consideration must be given to certain objective criteria to ensure a successful System. These are similar to the criteria used by the National Council of Marine Resources and Engineering Development in its approach to solving marine data problems. Based upon the needs of the Inshore Warfare support organization and other possible Navy users of shallow-water environmental data, these major objectives are[17]:

1. Determine the data requirements, end uses, aims, or mission applications of the environmental information provided by the data base.

2. Identify the specifications that govern the environmental information in its end use, aims, or application, including accuracy and limits of standardization.

3. Determine how the information with the data base is to be processed, converted, stored, and retrieved.

4. Determine how the data base information is to be disseminated; i.e., format, frequency, extracts, and urgency.

5. Determine how the user, or associated information subsystem, applies the information from the data base.

6. Specify the data acquisition system, sensors, networks, communications, and information processing system.

7. Acquire information for the data base according to a definite plan and with optimum economy.

8. Reassess the Inshore Warfare environmental data needs on regular or continuing basis.

The information in the NIWEIM System must be continually updated, revised, and modified to satisfy the Inshore Warfare Fleet and other user's needs. The subsystem data banks must be dynamic and responsive to user requests if it is to be even moderately successful. A running inventory of product requests, users, machine performance and product costs should be maintained to evaluate system operation at regular intervals during development and later when fully operational.

Product Example

Figure 9 shows a typical data support example from the NIWEIM System with four sample queries upon the system. The System design should anticipate such questions and provide for quick response time. For example, User No. 3 has requested planning guide information on beaches and harbors and expected surf for South Africa. The System should be set up to recall from the files an inventory of available data along the shores of South Africa. Figure 10 is an example of an output after the environmental effects have been computed. The System will be able to generate analog graphs and information charts of this type which the users can apply. Here results of a study of environmental constraints on world accessible landing sites, beaches and ports for the Fast Deployment Logistic Ship concept (FDLS) have been generated.

The building and maintenance of environmental effects information files are a vital feature of the System. The specification and formats needed for these files will require very careful systems engineering. Environmental effects files, which could be prototypes for NIWEIMS, are in use in the FADAP (Fleet ASW Data Analysis Program) and OPDATS (Operational Performance Data System) systems where post analyses of actual Fleet operations are evaluated against the detailed study of the actual marine environment that existed at the time of the maneuver or test. Fleet Numerical Weather Center (FNWC) was the primary designer and is custodian of these environmental files[15].

The environmental effects on a basic type of hardware was illustrated in Figure 5. In this case, sonar performance was used as an example.

Research Support of NIWEIMS

To achieve maximum long-range effectiveness of NIWEIMS, an advanced development program of fundamental and applied shallow ocean research is required to support the model System through its five-year development. One goal for the System is real-time prediction of the important environmental effects of shallow ocean parameters on weapon systems. A few air-sea parameters and their effects are now marginally predictable--forecasts are made, e.g., severe weather, tides, surf, winds, fog, and burial of objects on the seabed. There remains an abundance of marine environmental parameters that are not reliably predictable, e.g., shallow-water sound propagation, sea bottom reverberation, shallow-water waves (heights, slopes, directions, forces), shallow-water bottom pressure fluctuations, ambient noise, underwater visibility, electrical conductivity properties, turbulence, and the prediction of shallow-water transport, circulation, and bioluminescence over the continental shelves of the world.

Figure 11 shows the interrelation of research problem areas, and associated systems development problem areas within which the NIWEIM System should integrate research results to generate solution products.

Another paper of this meeting treats more directly and in greater detail the state-of-the-art of research in the related area of Coastal Environmental Prediction.

Cost, Time and System Performance

Cost-time relationships to develop the proposed model System are shown in Table 1. A five-year timetable was considered realistic and was based in part on the history of developing or establishing computer centers in Government. Funding is in terms of growth over the five-year period in fractions of a million dollars with an estimated total cost of 9.8 million. Estimates are based on figures provided by two sources: (1) computer and systems oriented personnel from in-house Navy, and (2) from industry. Figures allow for some inflation. In the fifth fiscal year, there would be a staff of approximately 40 persons to man and operate all functions of the proposed system prototype, except maintenance.

The performance objective of the proposed NIWEIM System is to provide a semi-automated model of a shallow-water environmental information management system in support of Navy Inshore Warfare missions within five years. Key to the effective retrieval of useful environmental products is a high-speed, time-sharing, third-generation digital computer with software capable of responding rapidly to user needs. The NIWEIM System will assess the quality or accuracy of the products disseminated and report it to the customer.

Alternate system approaches with trade-offs have been treated elsewhere for the proposal and will not be covered here. Some comparative cost data appear in Table 2. The research function (or subsystem) is an important system development segment comprising 15 to 20 percent of the total NIWEIM System cost.

The estimated cost of the five-year development period for the NIWEIM System Model is 9.8 million dollars. Manpower requirements would total 180 man-years of effort over the five-year period.

The development risk for the system is considered low. Computer hardware and software for many of the specified products are off-the-shelf items or are already in the scientific and Navy community. Experienced people capable of developing, operating, and maintaining the NIWEIM System are available in industry and the Navy. The mechanics of system development are assumed feasible.

The proposed system must interface with other computer-oriented data systems for effective no-delay input-output operation. The elimination of physical and functional constraints is crucial. During the five-year development program, careful consideration must be given to critical points that occur at man-machine, machine-machine, system-subsystem, and system-system interfaces to ensure compatibility and the smooth flow of information.

SUMMARY

The proposed Navy Inshore Warfare Environmental Information Management System (NIWEIMS) is essentially a software system. This System is within the present capability of equipment performance and computer technology. Its evolvement is assumed to be feasible. Due to the current and anticipated military threat to the security of this country, it is urgent that the proposed information management system be initiated. Delays in developing this or a similar system could jeopardize the Navy's shallow water defensive and effective capability, and waste additional time and money in developing suitable quick-fix hardware and tactics in the inshore areas. Cost reductions in developing effective hardware for weapons and sensors in the hostile shallow water marine environment could be substantial with the development of the NIWEIM System.

The performance capabilities of the NIWEIM System are summarized as follows:

1. The System will provide for the acquisition and analysis of raw data for shallow and narrow water environments of military interest.

2. The System must answer questions about inshore environment and the effects of such environment on inshore warfare weapons, sensors, and naval operations. Solving warfare system problems of the interrelationship of the marine environments and the

inshore operational technology is a primary aim of the system. Some of the System products will be digital computer products of statistical probabilities, environmental graphs, environmental guides for planning criteria, and environmental effect predictions for the use of the inshore warfare forces and engineer designers.

3. The generation of environmental effects information and data files for use in the System is a major portion of the system mechanism. This feature distinguishes this type of information management system from the standard environmental data centers.

4. The System must integrate environmental research and modern technology, especially in oceanography and marine sciences, into the information management system data bank in order to keep the information current, optimally stored, and cost effective. The System will help guide applied research along the objectives of the Inshore Warfare program.

5. The model System will have a steady, controlled growth toward an automated, highly responsive information retrieval system centered around modern computer sciences and information management. Since the System is evolutionary, and will involve both automated and manual information handling procedures, the growth design pattern and the man-machine interfaces through the development period must be carefully handled.

6. The System must seek to provide its users with a greater knowledge of the effects of the shallow water environmental factors; this knowledge must be cumulative and keep pace with the developing ocean science and weapon technology. Effort should be concentrated on environmental problems of Navy Inshore Warfare forces such as Mine Countermeasures, Amphibious Assault and Inshore Undersea Warfare, but not to the exclusion of all other user requirements, e.g., Navy R&D problems in the design of new weapon systems. System users must be kept informed of the state-of-the-art of pertinent environmental information in coastal waters. An updated System products catalog will be produced and distributed to potential customers.

7. Finally, because of the very nature of any data-gathering beast, the system cannot be permitted to accumulate, retain or store information or data for which there is no known use. The man segment in the system must be willing, or better yet, eager to discard obsolete or useless data. Holm[14] and Leblanc[16] both treat this problem in some depth.

RECOMMENDATION

It is recommended that the Navy (i.e., CNO) consider seriously the need for a NIWEIM System to deal with a backlog of shallow ocean-weapon system development problems. It is not particularly important who performs the task, what is recommended is that someone with the facilities, manpower and know-how treat this problem area soon.

ACKNOWLEDGMENTS

The assistance and counsel provided by CDR W. H. Williams, USN (RET), NSRDL, Panama City, Florida and Mr. W. Woodworth, Mellonics Corporation, Monterey, California, in the preparation of the basic document from which this report was derived are gratefully acknowledged.

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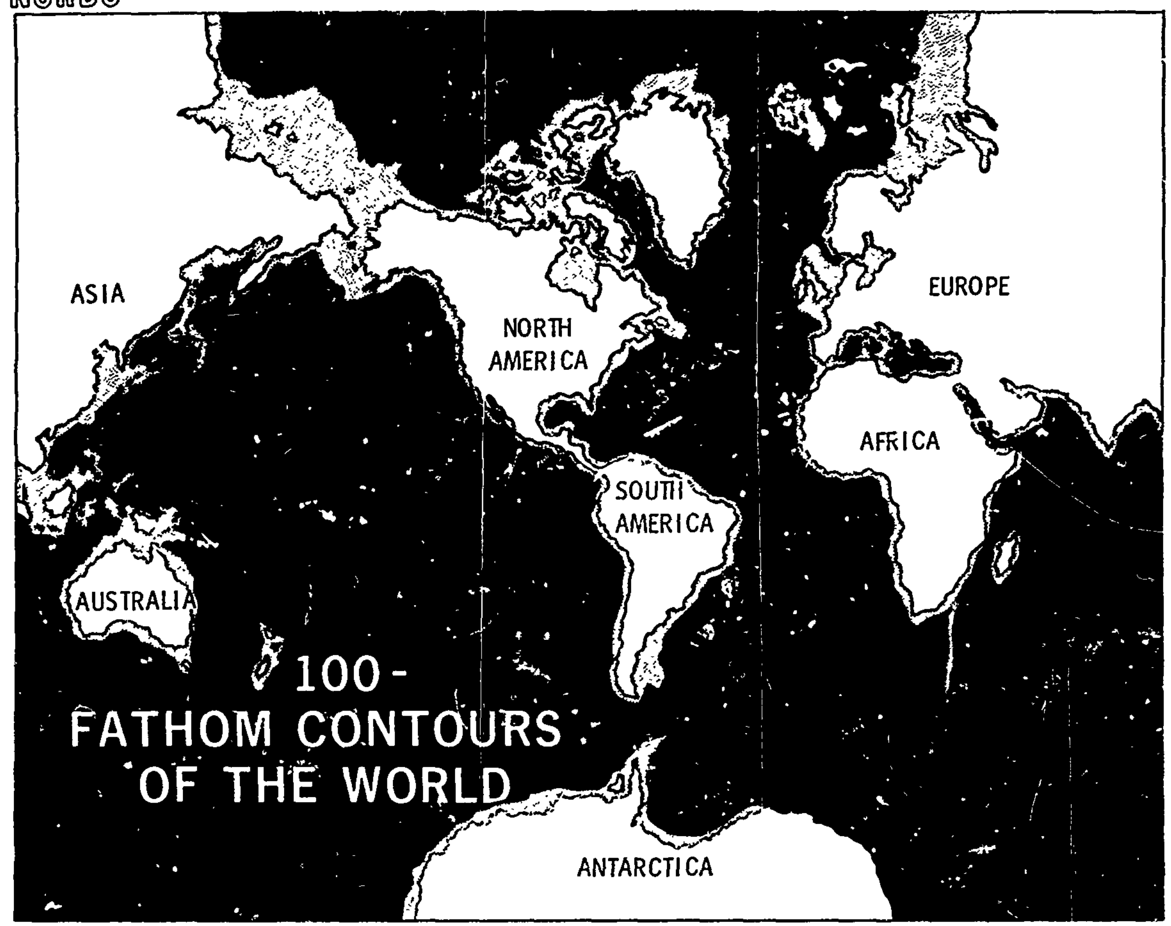

Figure 1
Shallow Ocean Areas of the World

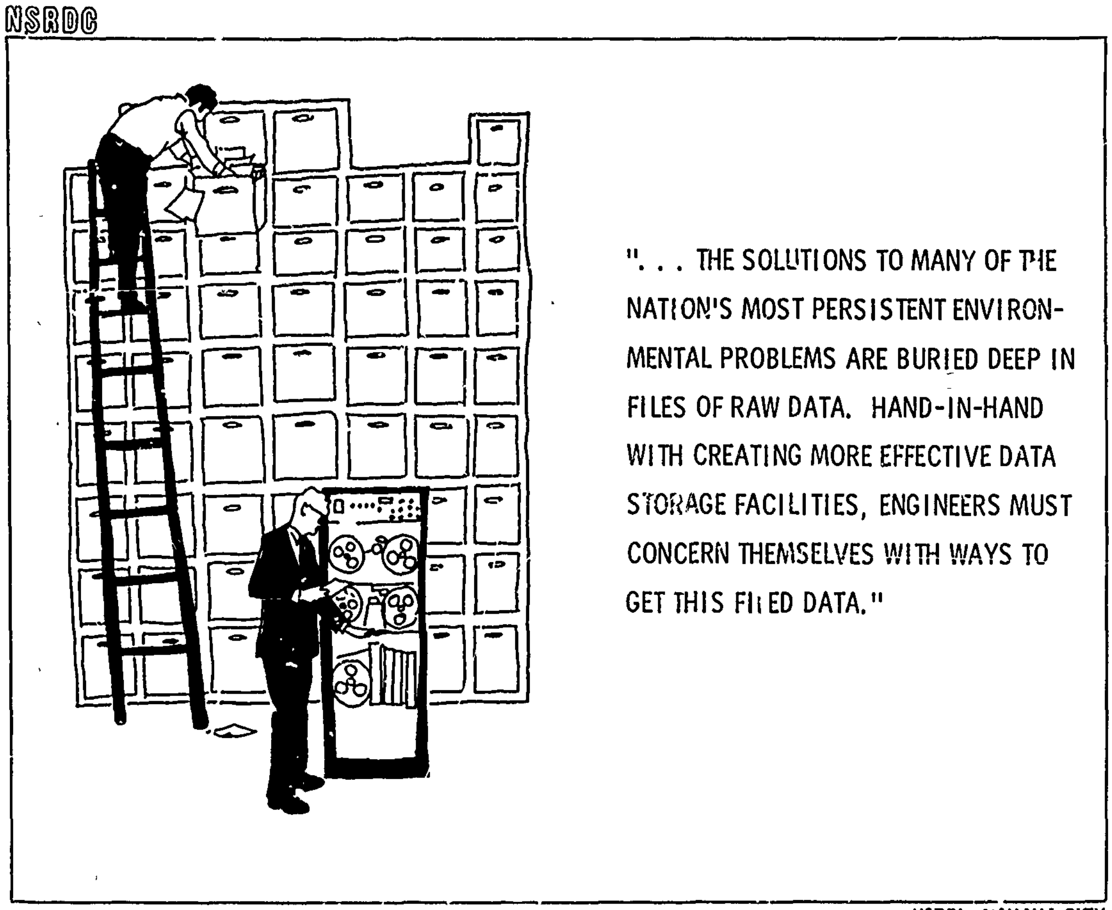

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Figure 2
The Environmental Data Problem

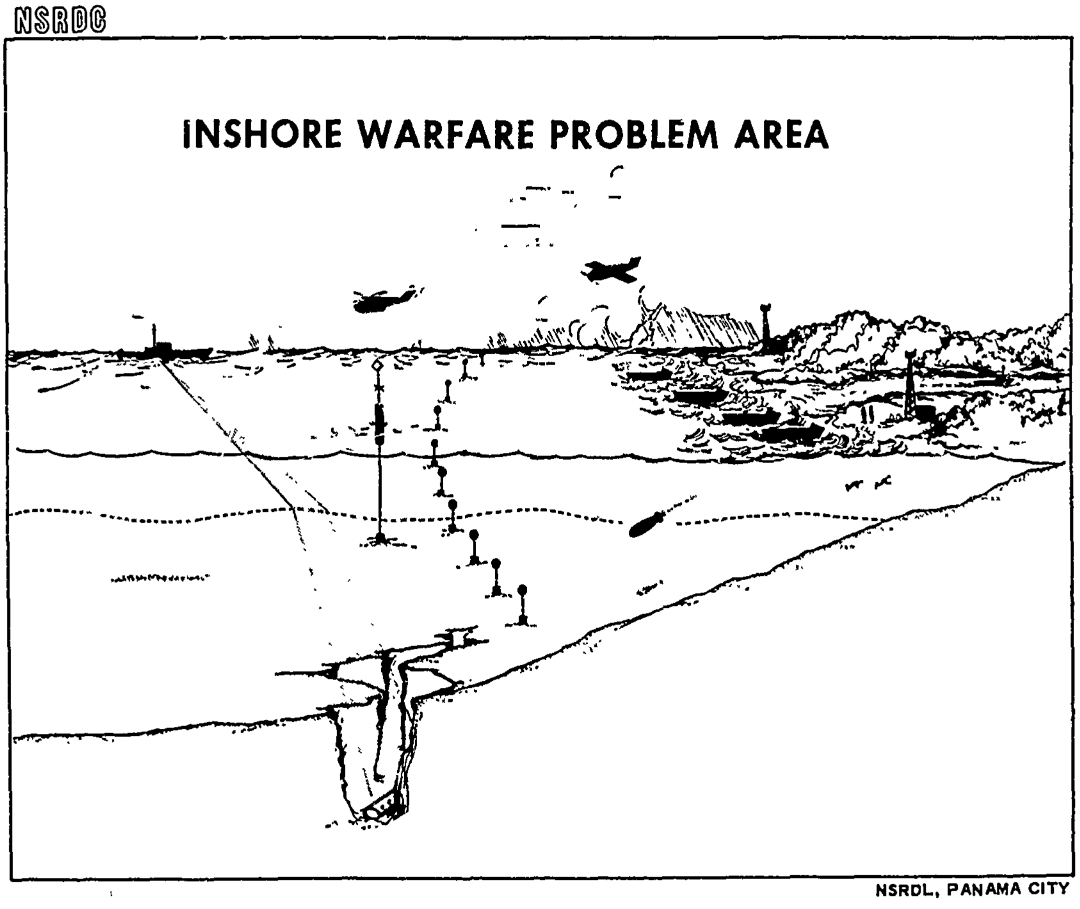

Figure 3
The Inshore Warfare Problem Area

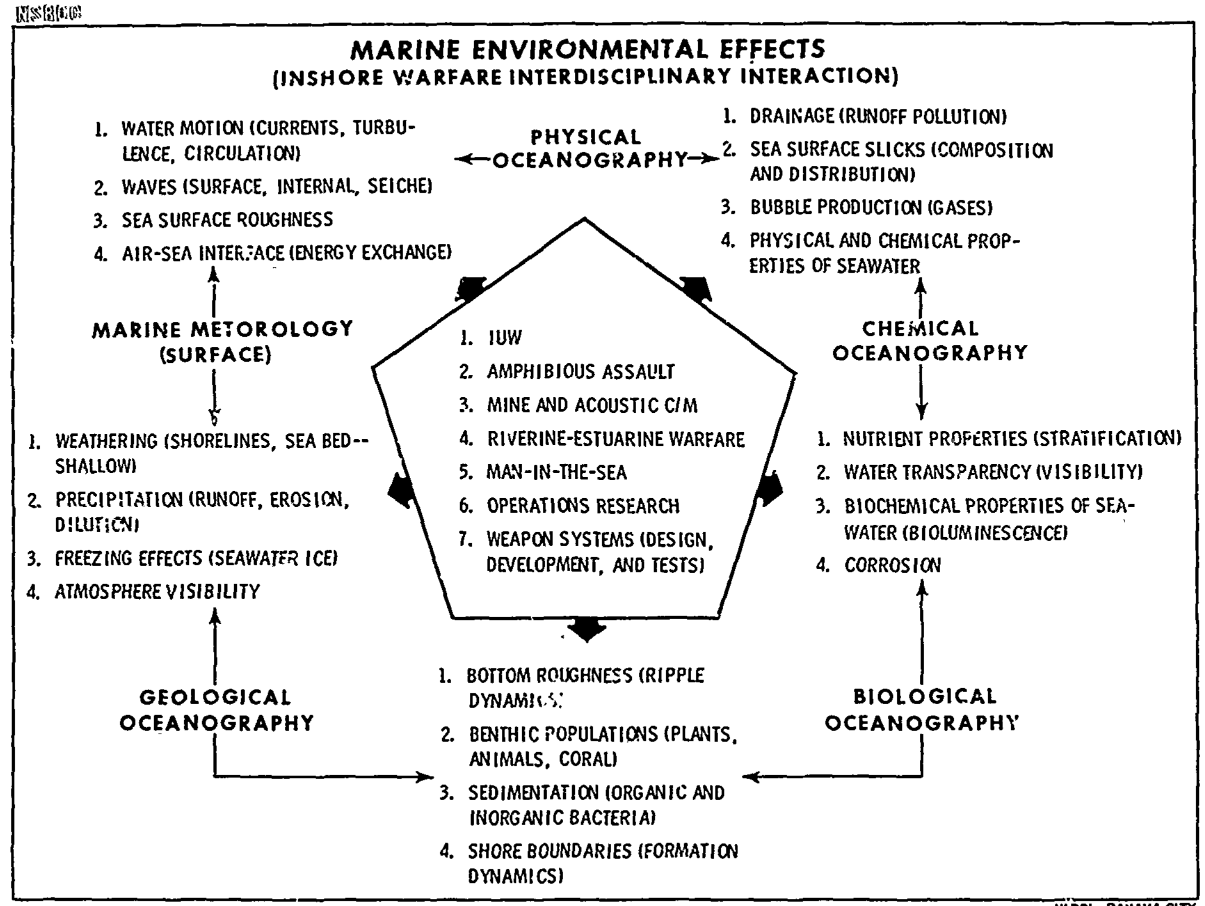

Figure 4
Interdisciplinary Interaction Problem of Inshore Warfare

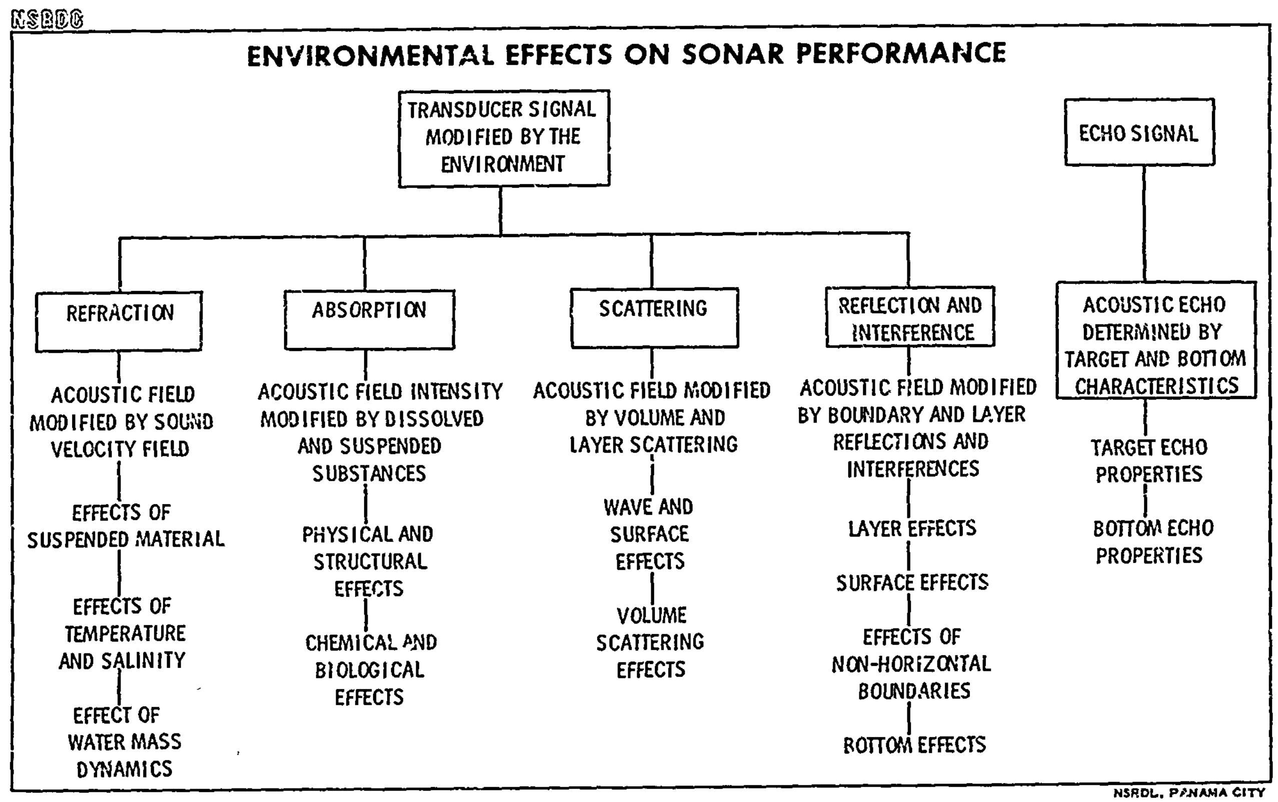

Figure 3
Environmental Effects and Sonar Performance

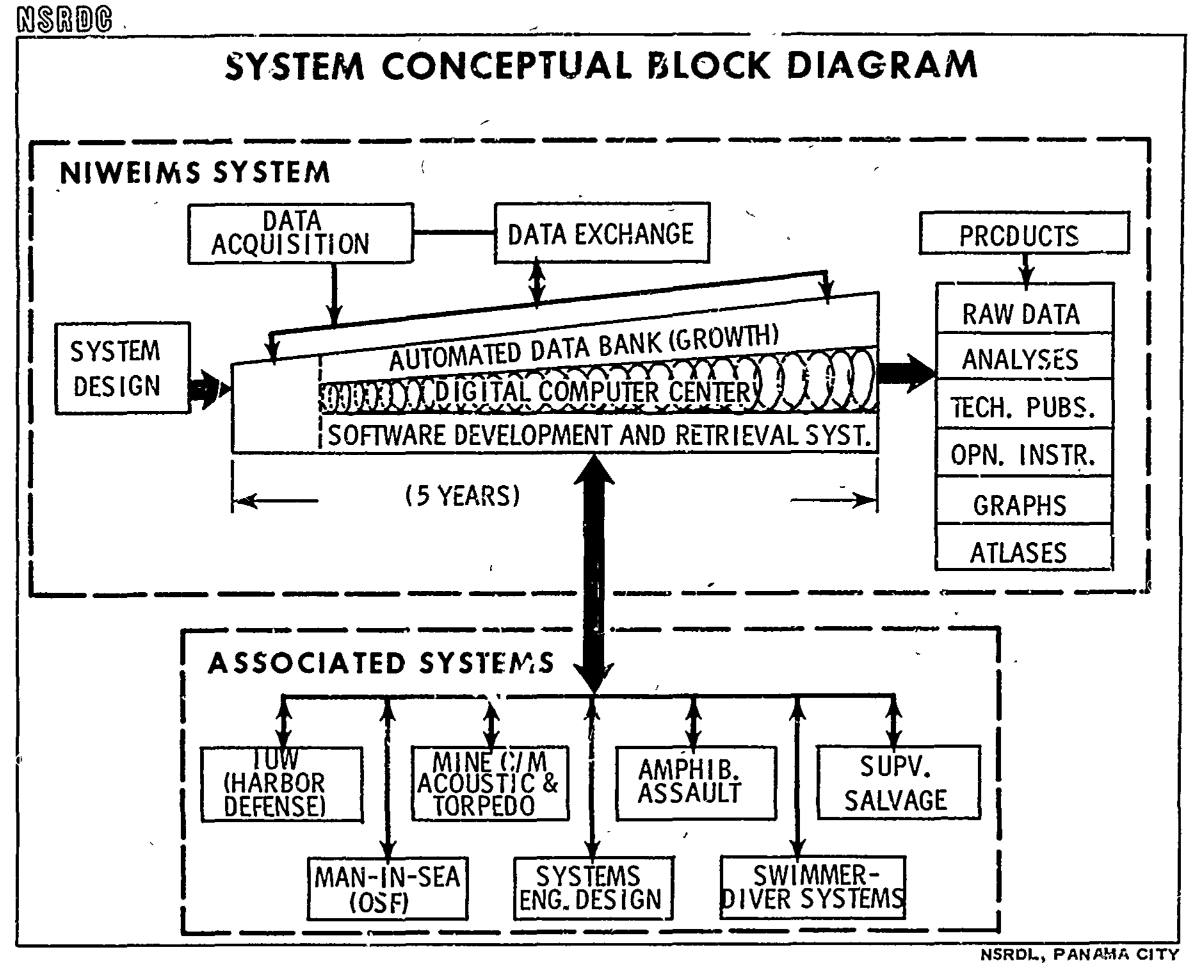

Figure 6
NIWEIMS Concept (Block Diagram)

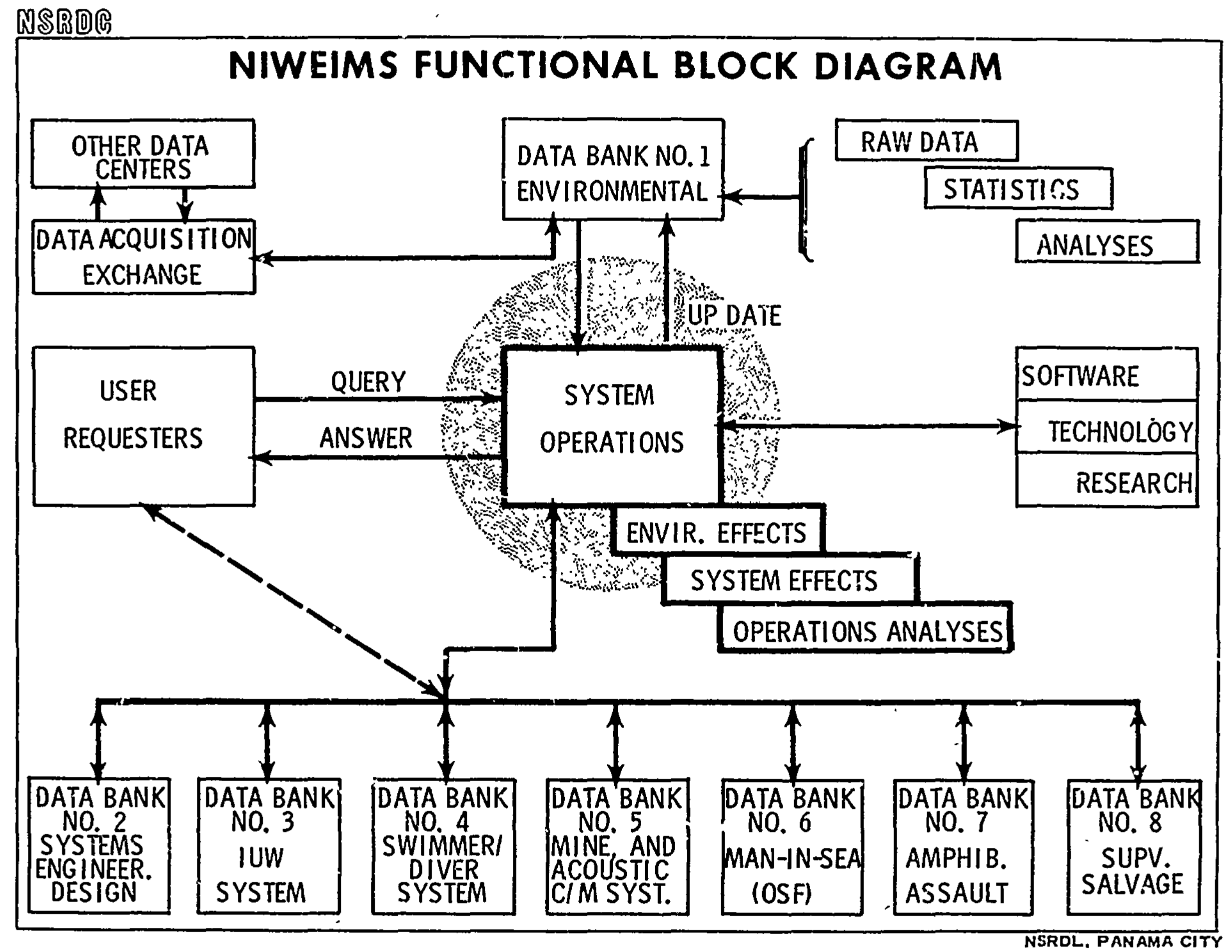

Figure 7
NIWEIMS Functions (Block Diagram)

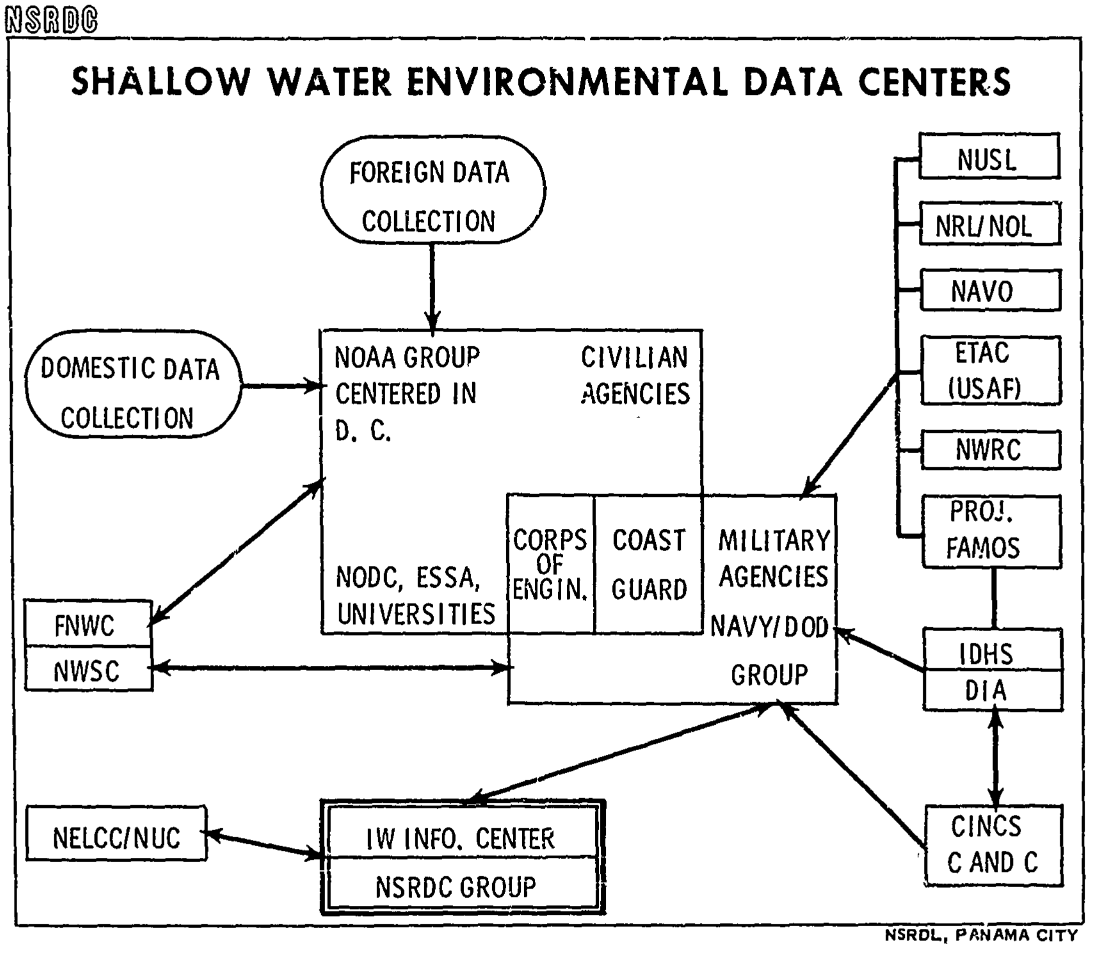

Figure 8
Shallow Water Environmental Data Sources

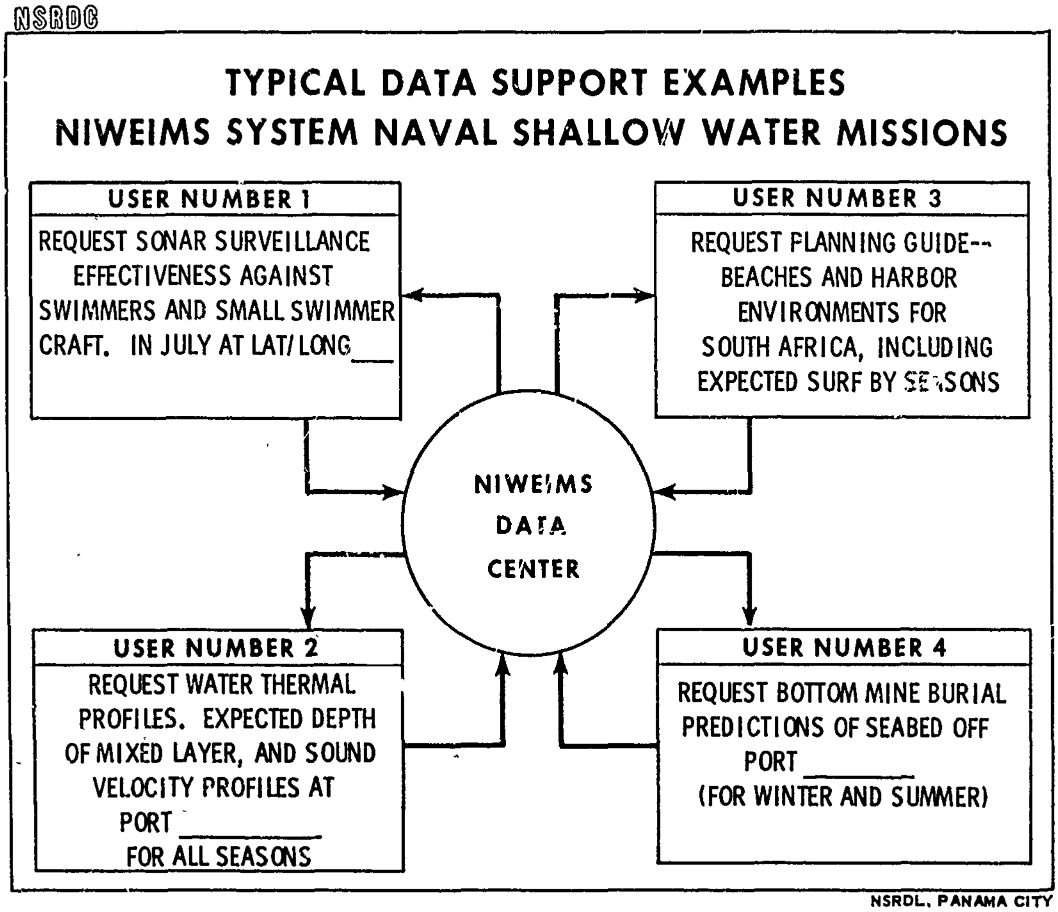

Figure 9
NIWEIM System Data Support Examples

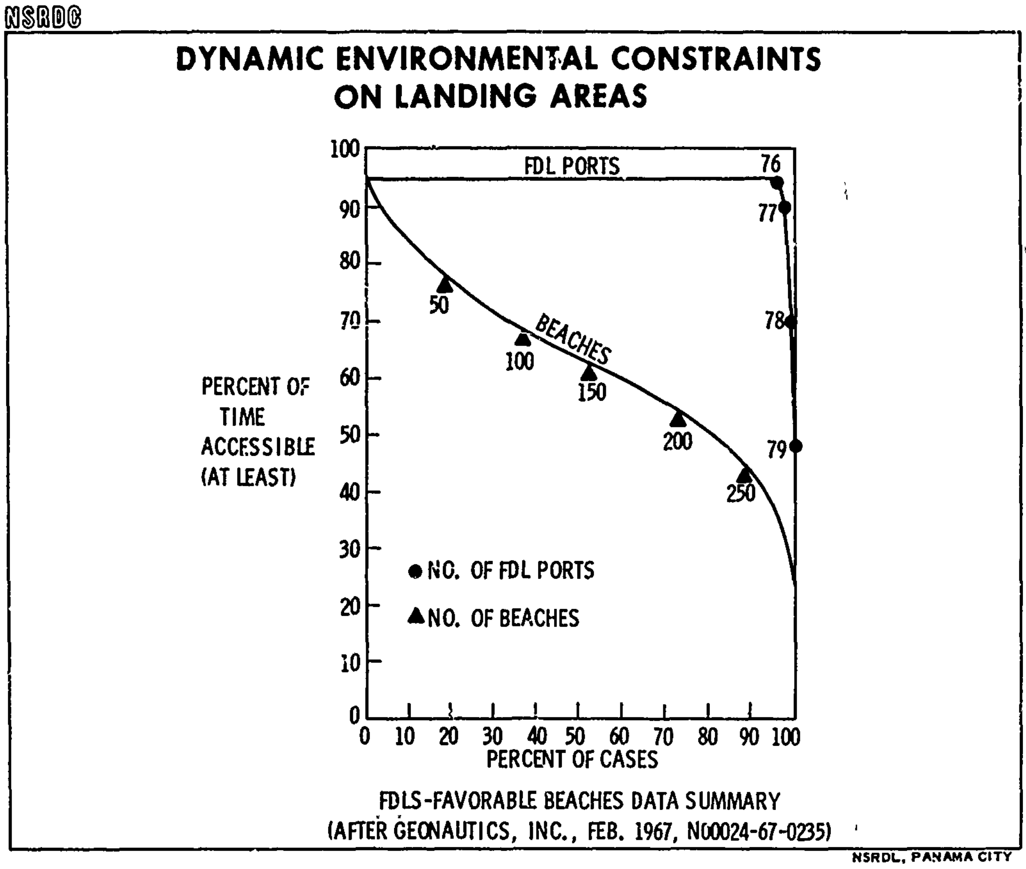

Figure 10
NIWEIM Product Example Extracted from Technical Literature

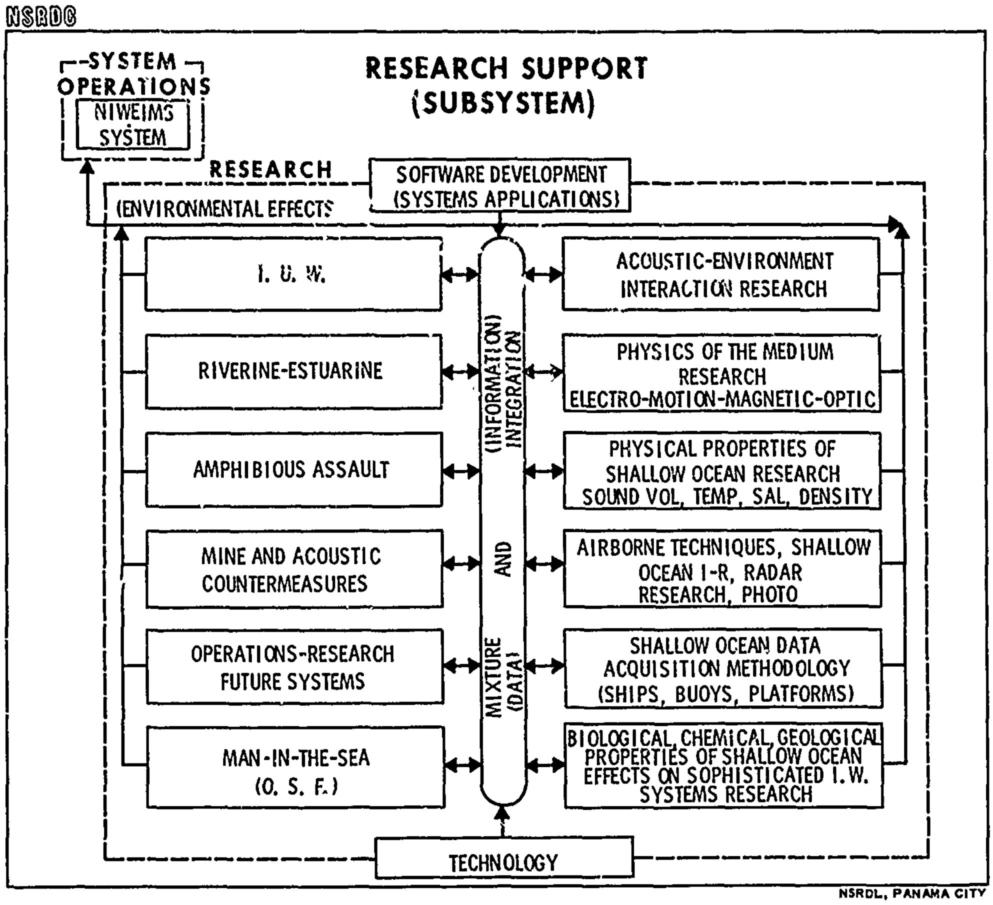

Figure 11
The Research Support Functions

Table 1

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PROPOSED MODEL NIWEIMS SYSTEM COST–TIME TABLE–5 YEARS

	$M					TOTALS	
	FY 1	FY 2	FY 3	FY 4	FY 5	$M	PERCENT
COMPUTER OPERATION (STAFFING)			0.909	0.180	0.300	0.570	5.8
COMPUTER RENTAL SITE PREPARATION COMPUTER TIME		0.350	0.360	0.440	0.540	1.690	17.3
SYSTEMS AND APPLICATIONS PROGRAMMING (SOFTWARE)	0.50	.150	.350	.500	.540	1.590	16.3
PROBLEM DEFINITIONS SYSTEMS SPECIFICATIONS ANALYSES	.320	.360	.400	.440	.480	2.000	20.5
DATA ACQUISITION AND EXCHANGE	.200	.400	.600	.600	.650	2.450	25.1
ENVIRONMENT-EFFECTS RESEARCH	.200	.260	.300	.300	.400	1.460	15.0
TOTALS	0.770	1.520	2.100	2.460	2.910	9.760	100.0

NOTE: COMPUTER COSTS BASED ON TWO-SHIFT RENTAL EXPERIENCE. DATA ACQUISITION COSTS ESTIMATE BASED IN PART ON FNWC AND NODC EXPERIENCE. RESEARCH COSTS ARE IN-HOUSE NAVY LABORATORY EXPERIENCE.

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Table 2

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NIWEIMS SYSTEM—EVALUATION TABLE

CRITERIA	BASIC SYSTEM	% OF TOTAL	ALTERNATE SYSTEM A	% OF TOTAL	ALTERNATE SYSTEM B	% OF TOTAL
A. PERFORMANCE FACTORS						
1. DATA ACQUISITION AND EXCHANGE	HEAVY - EARLY YEAR	25	STRETCH OUT PROGRAM SLOW DATA ACQUISITION	30	HEAVY RELIANCE UPON NAVY WEATHER SERVICE AND FNWC	10
2. OUTPUT ANSWERS	PLANNED ANSWERS EARLY NEAR REAL-TIME ANSWERS TOWARD END	15	FIRST 5 YEARS MOSTLY STANDARD OUTPUTS	15	MOD. DEVELOPMENT STANDARD OUTPUT PRODUCTS	15
3. PRODUCE ENVIRONMENTAL EFFECTS FILES	HEAVY EFFORT STARTS THIRD YEAR	20	SELECTED CONCENTRATION ON FEW PARAMETERS AND SENSORS - RESTRICTIVE	20	HEAVY EFFORT STARTS IN SECOND YEAR. HEAVY RELIANCE ON OUTSIDE CENTERS	25
4. INTEGRATE ENVIRONMENTAL SCIENTIFIC RESEARCH	BALANCED RESEARCH (BASIC AND APPLIED) STEADY GROWTH	15	LESS RESEARCH/YEAR FUNDING THAN BASIC SYSTEM; NO GROWTH; TOKEN EFFORT	15	MORE PERCENT FUNDING FOR BALANCED STEADY GROWTH	20
5. AUTOMATION GROWTH	MODERATE FILE BUILDUP AND AUTOMATION GROWTH	10	SLOW FILE BUILDUP AND AUTOMATION	5	MODERATE BUILDUP	5
6. ENVIRONMENTAL KNOWLEDGE SHALLOW WATER AREAS	INCREASED KNOWLEDGE STEADY GROWTH	15	SLOW KNOWLEDGE ACCUMULATION; HIGHLY SELECTIVE	15	MODERATE ACCUMULATION	25
B. COSTS	$9.76M		$12M		$8M	
C. SCHEDULE - COMPLETE	5 YEARS		10 YEARS		5 YEARS	
D. DEVELOPMENTAL RISK	LOW		MODERATE		LOW - MODERATE	

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THE SIGNIFICANCE OF WAVE REFRACTION ACCORDING TO GROUP VELOCITY

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ABSTRACT

An analysis of the direction-power spectra of gravity water waves in the coastal waters of Panama City, Florida, indicates that refraction studies must be carried out with group velocity instead of the customary phase velocity. The importance of this to the question of how wave energy due to distant storms is distributed along a coast is reviewed. It is found that storms located in deep water within a certain range of directions from a coastal point have waves which turn back toward deep water before reaching shore at the coastal point. The closest distance of approach to shore is specified by the direction locating the storm with respect to the coastal point and the period of the waves. This is seen to be of importance to the positioning of coastal structures, the protection of beaches from erosion, and the landing of ships. It is found that waves can be trapped in coastal waters by reflection at the beach and refraction at intermediate depths. If the coast has a steep embankment or shelf of fairly constant depth the trapped waves have an upper limit cutoff frequency. Examples illustrating these ideas will be presented.

INTRODUCTION

Regardless of the direction from which gravity water waves originate, as they run into shallow water they have a tendency to turn so that the wave crests are parallel to shore upon reaching the beach. This phenomenon is called wave refraction. It occurs when a wave crest approaches the coast at an angle, for different parts of the crest are in different water depths at the same time and therefore moving with different velocities.

A theory of wave refraction is a theory of where wave energy goes. It explains why surf conditions can be so different on nearby beaches. It indicates the most favorable sites for the location of boat docks, piers, and breakwaters. It tells us the distribution of wave energy along a coast, and is therefore an important factor for both short time endeavors such as amphibious assaults and phenomena on a geological time scale such as the alteration of coast lines.

Until recently we thought we understood the refraction of gravity water waves. But with the advance of measurement techniques, more sophisticated mathematics, and the advent of the computer, we are now in a position to test hypotheses to an accuracy Newton could only dream of. As a result, the current textbook approach to wave refraction has been called into question.

An outgrowth of wave research connected with amphibious assaults during the Second World War was the concept of "significant waves." The idea was introduced by Sverdrup and Munk (1947). This concept plus the analysis of empirical data on sea conditions (Jasper, 1956) showed that a particular sea condition could be specified by a Rayleigh distribution of wave heights. From the viewpoint of significant waves, the wave propagation characteristics are based on a single period and a single wave height.

When one looks at the sea surface he does not find a wave of a single frequency. At best he finds a fairly regular wave train including a narrow spectrum of frequencies and coming from a narrow range of directions. The wave crests are not infinite in length and the waves appear with such order only for short periods of time. More often we observe the confused sea which involves many frequencies and directions. Pierson, Neumann, and James stress in the H. O. Publication No. 603 that we cannot account for the refraction effects of storm waves using just one wave period. The ray paths of different periods can vary considerably.

Much progress was made when power spectra was computed from wave records. Using power spectra, we associate with the sea surface a spectrum of frequencies and to each frequency is assigned a corresponding energy. Unfortunately, nothing is said about wave directions. For that we need directional-power spectra.

Munk, et al (1963), report that it is now possible, using an array of pressure sensors, to determine the direction of swell to within a few degrees. Such accuracy is possible even when the wave heights are no greater than a few millimeters. If the array has three or more sensors it is even possible to distinguish between several sources within the same frequency band. This feature is particularly important if one is to separate wave reflections from a coast from direct arrivals coming from offshore.

Munk, et al (1963), computed the wave-inferred directions of distant storms accounting for refraction effects. They utilized the conventional approach which is based on phase velocity. Phase velocity is the velocity with which individual waves propagate. They did not find good agreement with observations. In fact, they state: "There is a curious indication that the wave-inferred directions are to the left of the location obtained from weather maps."

Wave measurements have been collected in the Gulf of Mexico near Panama City, Florida, by Austin. Directional-power spectra for the data have been obtained by Bennett, et al (1964, 1968). A computer program for wave refraction has been established by Matson and Howard following Wilson (1966). Refraction of the waves according to phase velocity shows discrepancies similar to those found by Munk. However, the error is increased by virtue of the wave recorders being placed in shallower water depths.

THE CUTOFF FREQUENCY - A HINT?

Having found the existing textbook approach to gravity water wave refraction to provide unsatisfactory results, we find it necessary to seek a fruitful approach. A hint to the nature of the refraction law is provided by a study of wave records collected at the sites of two offshore stages near Panama City, Florida. On a number of occasions a series of low frequency waves with an upper limit cutoff frequency of 0.075 Hz have been observed. The directions of these waves indicate they were reflected from shore. It is interesting to note that the same cutoff frequency is found in measurements of the magnetic field induced by the gravity water waves (Wynn and Trantham, 1968).

In addition to the question presented by the cutoff frequency, measurement of these low frequency waves emphasize the importance of reflected wave energy. It also illustrates the need for utilizing measurement techniques which can account simultaneously for both offshore wave arrivals and reflections from shore.

Unfortunately, not enough is known about the reflection of gravity water waves. All too often the problem is dismissed by a statement that steep banks reflect remarkably well. Munk, et al (1963), obtained the first measurements of reflected wave energy in a natural environment. They found that for wave periods greater than 33.3 seconds the western shore of San Clemente Island reflects most of the wave energy. Laboratory studies

(Wiegel, 1964) show that as the slope of the reflecting boundary is decreased from the vertical the amount of reflected wave energy decreases quite rapidly. At the same time, the amount of energy expended through the breaking of waves increases rapidly. Further, a phase shift between the incident and reflected waves is found to develop. The state of the art is such that we have the means to answer many questions concerning the reflection of waves in coastal waters. The observation that for some frequencies there can be nearly complete reflection points to the need for further examination of this matter.

Reflected waves with a cutoff frequency suggests the possibility of trapped waves. Using the concept of phase velocity, Issacs, et al (1951), have shown that for certain reflection angles, waves can be turned back toward shore through refraction at intermediate water depths. By this process the waves can skip along the coast. If we now introduce a shelf, a cutoff frequency arises. For frequencies greater than a certain value the water depth is too great for refraction effects to take place. On the basis of phase velocity, the required shelf depth for the observed cutoff frequency of 0.075 Hz in the Panama City waters is of order 450 feet. The charts do not show such a feature.

Difficulty with phase velocity has been encountered before regarding the computation of travel time. In the last century hydrodynamicists used phase velocity to predict the time of arrival of storm waves. Observation showed these predictions to be incorrect. Instead, agreement was found only when it was realized that waves propagate as groups with a spectrum of frequencies. The corresponding group velocity, which is identified with the transport of energy, has been verified as giving the correct time of arrival of storm waves.

An important point to note here is that the correct law for giving the time of passage of gravity water waves was gained only when someone got out his stop watch and collected data for careful study. The theory came later. In fact, even today there is not general agreement on the physical significance of the several existing group velocity definitions. Does one rely on the kinematic definition based on wave interference, the definition based on the wave energy propagated, or a definition considering a change in wavelength with propagation distance?

The fact that energy travels with group velocity encourages us to consider wave refraction hypotheses that involve group velocity. Unlike phase velocity, which has the greatest value in deep water (water depth greater than one-half the wavelength), group velocity has a maximum value at an intermediate water depth (ratio of water depth to wavelength equals 0.189). Due to this maximum value there is the possibility of waves being trapped in coastal waters. The observed cutoff frequency of 0.075 Hz can be justified by a shelf depth of 140 feet. The bottom profile of the Panama City waters is shown in Figure 1. There is a rapid drop off in depth at a distance of about 40 miles. Between 15 miles and 40 miles, the water depth does not vary more than about 25 feet from the predicted 140 feet. This geological feature is the result of a past coastline.

TRAVEL PATHS USING GROUP VELOCITY

The above agreement, although remarkable, does not in itself prove that we indeed did observe trapped waves as described with refraction according to a group velocity scheme. However, the results are sufficiently encouraging to hindcast recorded waves using group velocity to see if travel paths lead back to the region of wave generation.

Two group velocity models are under study. Both involve the concept of wave groups, or packets, where individual waves move through the packet with phase velocity.

Williams and Isaacs (1952) considered the refraction of wave groups following a method proposed by Stoneley (1935). Here an element of the energy front moves with group velocity, but its direction is normal to the individual wavefront at the element in question. Because of the involvement of group velocity, refraction according to this hypothesis leads to results quite different from the phase velocity calculations. The Stoneley approach to wave refraction, although offered 35 years ago has largely been ignored. The correctness and possible range of validity of this hypothesis is now under careful review.

We have considered a similar group velocity hypothesis. An element of the energy is considered to move normal to the energy front. The direction of the wave-packet and the direction of the individual waves it contains is assumed to be the same at the place of wave generation. This approach has been applied to wave data collected the summer 1965.

As an example, we consider waves recorded 1 June 1965 for the time period 1154-1226. One obtains swell with a peak power near 0.1 Hz. Both the power density and directions of these waves vary in a smooth fashion. Accordingly, we suspect the waves had a common source of origin. The high frequency waves present show little refraction and hence indicate the direction of the source. In this case the waves came from near south. The test comes in accounting for the refraction effects of the low frequencies to see if they can be attributed as due to the same source. In Figure 2 we have obtained the ray paths following the currently accepted approach using phase velocity. Each ray represents a different period. Number 1 has a period of 6.7 seconds. The rays increase with period to Number 13 which represents 20 seconds. It is not possible to assign the waves plotted in this manner to a common source. In Figure 3 we have computed the ray trajectories using group velocity. The result appears to be more reasonable. With the exception of Ray Number 11, which depicts the 15-second period, the rays have a tendency to go south through the Yucatan Channel to the Carribean Sea.

Recently, an analysis has been made of wave measurements of Hurricane Betsy (1965). The storm was considered when it was in the Gulf of Mexico just west of the tip of southern Florida. It was found using phase velocity that the periods which are short and undergo little refraction go back in the general direction of the storm path. But once refraction becomes important the rays end up north of Tampa. The agreement with observation is very poor. However, with refraction using group velocity the rays extend back to the path of the hurricane even for long periods.

The hypothesis that the refraction of gravity water waves must involve group velocity seems strengthened. There are questions which remain to be answered, particularly as regards theory. But these results serve to indicate the direction our future research should take.

It is interesting to consider the propagation of wave groups from deep water to shore. Consider Figure 4 in which the rays are drawn using group velocity. The depth contours are parallel to shore and the water depth increases as one goes away from shore. The deep water angles of incidence are measured by the angle between the packet velocity vector and the normal to the depth contours. For deep water angles of incidence between 0 and 56.5° the wave-packets follow paths such that the angles increase to the depth of the group velocity maximum, undergo a point of inflection, and then decrease shoreward. For deep water angles of incidence equal to or greater than 56.5° the wave-packet paths have turning points such that the packets proceed back into deep water. From this we have the conclusion that if a storm were located in deep water at a sufficient angle to a coastal town, the wave energy could follow paths such as to avoid the town. This example illustrates a pronounced difference in comparison with phase velocity for which such behavior would not be possible.

CONCLUSIONS

In conclusion, we have found that the refraction of gravity water waves cannot be explained on the basis of phase velocity. A refraction law involving group velocity is indicated. With group velocity we can account for phenomena that cannot be accounted for on the basis of phase velocity. Verification of the exact nature of the law and the theoretical consequences remain to be established. Practical consequences of this work include the positioning of coastal structures, the protection of beaches from erosion, and the landing of ships.

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APPENDIX

The wave measurements were made on the sea floor at the site of Stage I. This offshore stage is located at a water depth of 104 feet in the Gulf of Mexico about 11 miles from shore near Panama City, Florida. The directional-power spectra refer to the individual waves which move with phase velocity. The bearings obtained from the analysis represent the directions from which the waves approach Stage I. To find the corresponding wave-packet bearings we apply Snell's law independently to the wave-packet and the individual waves. We let θ be the angle between the packet velocity vector and the normal to the depth contour. The corresponding angle for the individual waves is γ. We let the subscript g denote the water depth at the place of wave generation and assume $\theta_g = \gamma_g$. If the subscript 1 refers to the place of measurement we have

$$\frac{\sin \theta_1}{G_1} = \frac{\sin \theta_g}{G_g}$$

$$\frac{\sin \gamma_1}{C_1} = \frac{\sin \gamma_g}{C_g} .$$

These relations combine to give

$$\sin \theta_1 = \frac{C_g}{G_g}\frac{G_1}{C_1} \sin \gamma_1 . \tag{1}$$

The wave-packet bearings were calculated using Equation (1) on the assumption that the Stage I depth contour could be approximated by a straight line having an angle of 131 degrees with respect to north. Also, it was assumed that the wave generation water depth for the summer 1965 data was deep water. Table 1 shows for selected periods the measured bearings, computed wave-packet bearings, and the deep water refracted bearings according to both phase velocity and group velocity. The deep water bearings refer to the refraction figures in the text.

Period (sec)	Bearing Measured (degrees)	Packet Bearing (degrees)	Deep Water Bearing Phase Velocity (degrees)	Deep Water Bearing Group Velocity (degrees)
6.667	183.82	182.17	183.67	183.90
7.059	184.82	182.22	184.31	185.89
7.500	182.00	177.70	180.70	183.69
8.000	178.75	171.32	175.26	185.00
8.571	179.66	169.07	174.48	186.34
9.231	182.49	169.85	176.23	185.73
10.00	184.77	169.28	173.21	181.17
10.91	186.43	168.03	169.05	177.43
12.00	188.83	169.45	164.35	172.95
13.33	196.60	180.45	184.55	183.80
15.00	235.80	196.00	235.78	199.94
17.14	243.73	179.20	251.43	178.92
20.00	242.11	180.72	--	176.59

Stage I 1 June 1965 Time - 1154-1226

TABLE 1

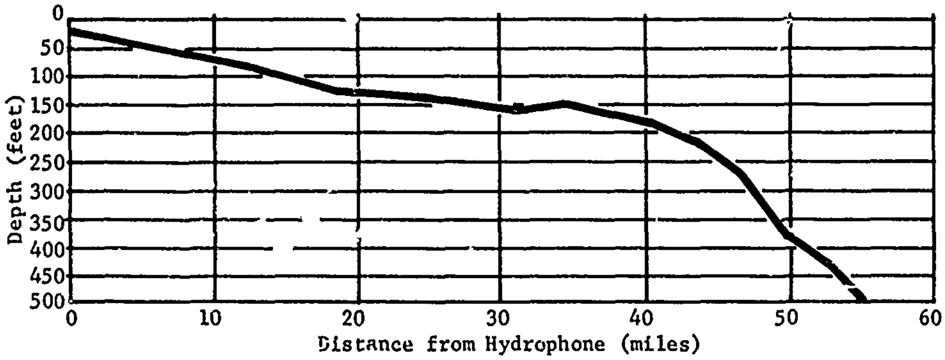
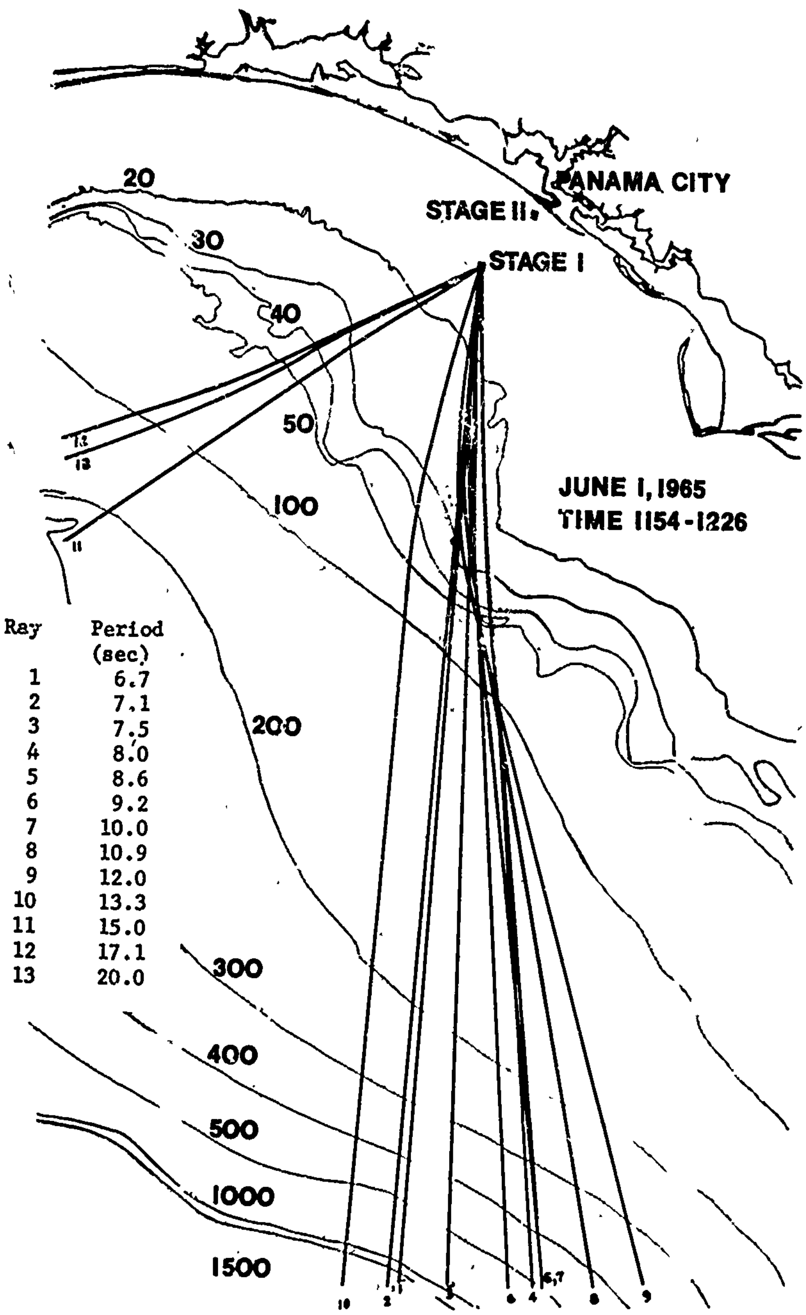
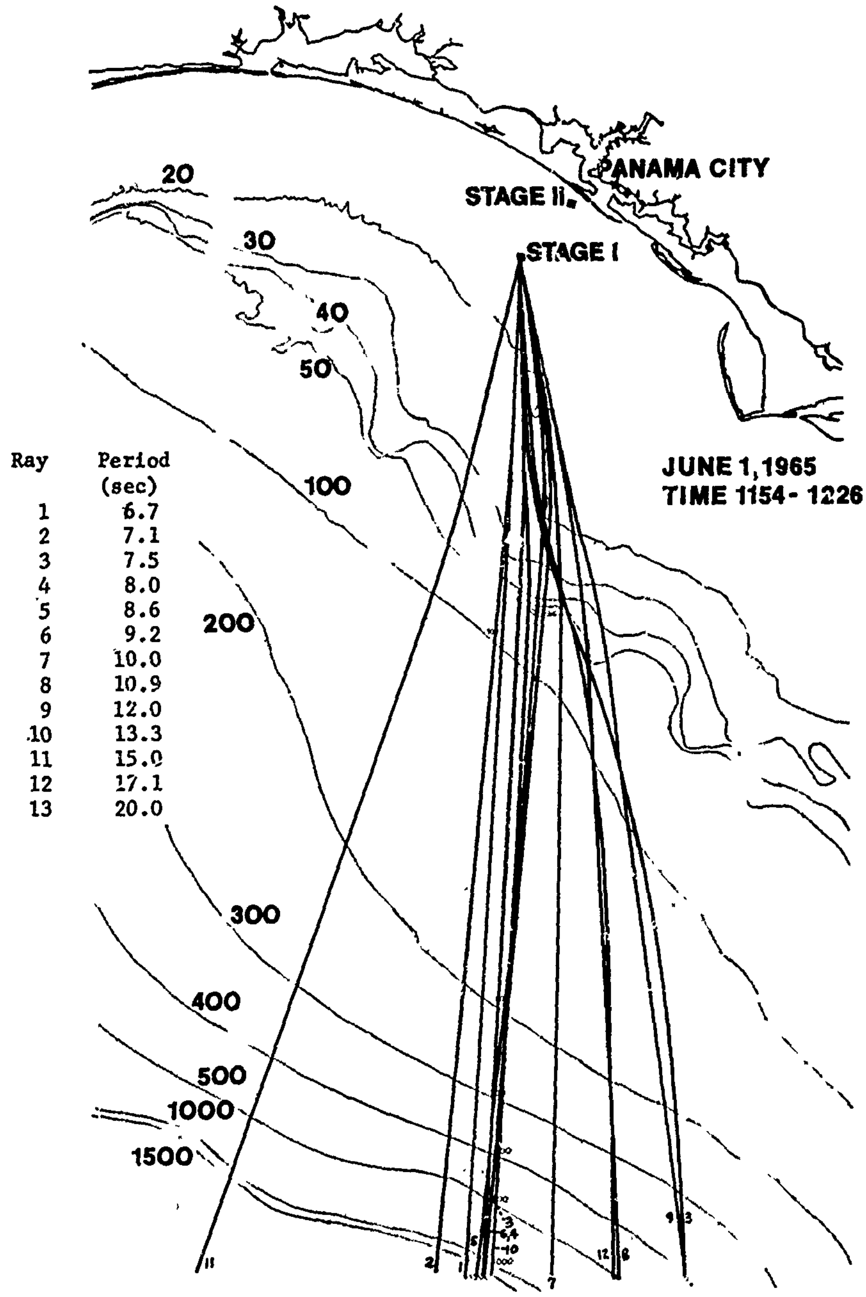


FIGURE 1. DEPTH PROFILE PANAMA CITY, FLORIDA



Ray	Period (sec)
1	6.7
2	7.1
3	7.5
4	8.0
5	8.6
6	9.2
7	10.0
8	10.9
9	12.0
10	13.3
11	15.0
12	17.1
13	20.0

Figure 2. Phase Velocity Refraction



Ray	Period (sec)
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6	9.2
7	10.0
8	10.9
9	12.0
10	13.3
11	15.0
12	17.1
13	20.0

Figure 3. Group Velocity Refraction

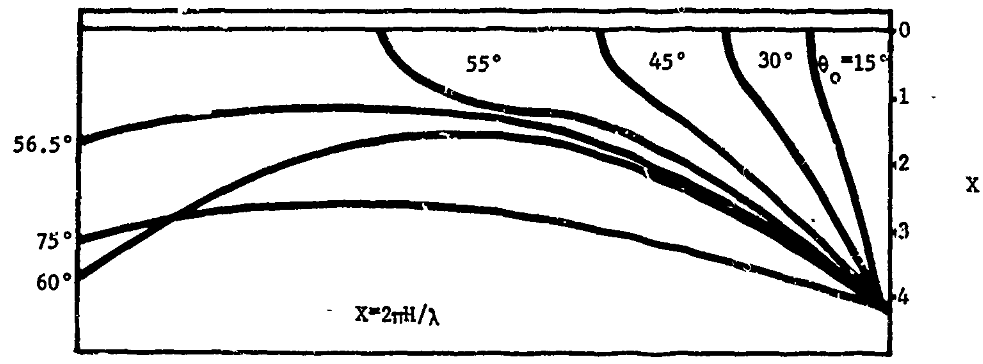

FIGURE 4. GROUP VELOCITY REFRACTION FOR PARALLEL DEPTH CONTOURS

Knowledge of Deep Ocean Vehicle Operations

DESIGN STUDY OF A SCIENTIFIC RESEARCH SUBMERSIBLE SYSTEM SRS-20,000

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ABSTRACT

Starting with a statement of needed performance capabilities for manned scientific missions to twenty thousand feet, the paper explores the system design approaches, materials and equipments which could best satisfy these needs within present and immediate future state-of-the-art.

The paper describes potential surface support ship conversions, or new construction options and provides a set of target ship characteristics and performance requirements. A concept for a new construction ship, plus the modifications to existing ships which would be necessary to meet these requirements, are discussed.

Basic parameters governing the effectiveness of a manned deep submersible system in carrying out the desired missions are defined. The basic problems in satisfying these parameters are reviewed and each major area of manned deep submersible design is discussed. These include: size, configuration and form, buoyancy control, trim, materials, structure, propulsion and maneuvering, electrical propulsion systems, primary power sources, life support, optics, sphere layout and human factors, vehicle instrumentation.

Design concepts for the submersible are presented, developed from the various system options and the individual choices made in the areas discussed above.

The paper concludes that it is possible today to develop a highly effective scientific research system for twenty thousand foot depths.

1. SCOPE

The paper covers the significant results of a concept design study undertaken for the Naval Ship Systems Command (OOVIK) under the management of PMS381D. The study was made to determine the optimum directions for development of a scientific research submersible system design for depths to 20,000 feet, known hereafter as SRS-20,000. The system was to meet the needs of the naval laboratories in their world-wide ocean research programs over the next fifteen years.

2. THE SCIENTIFIC RESEARCH SUBMERSIBLE AND SUPPORT SYSTEM STUDY PLAN

The concepts of a towed SRS-20,000 versus that of a surface-ship-supported SRS-20,000 were developed and explored. The characteristics of the SRS-20,000 and its support ship were defined. Each type of support ship (towed, self-propelled, conversion and new construction) and methods of handling the SRS-20,000 were reviewed. Studies were made concurrently of the vehicle pressure sphere and float structure with particular emphasis on material, stability, fabrication and structural integrity. All subsystems including propulsion, buoyancy and trim, maneuvering, life support, electrical and power were investigated and evaluated.

3. OBJECTIVES OF THE SCIENTIFIC RESEARCH SUBMERSIBLE SYSTEM

The needs of the laboratories are to accomplish the following objectives at depths to 20,000 feet using equipment within the state-of-the-art during the next five years:

a. Hovering, maneuvering, sample taking and small object recovery.

b. Monitoring continuously the gross chemistry of the passing seawater.

c. Searching by optical and acoustical means.

d. Studying physical and biological strata enroute.

e. Photographing with equipment operating in conjunction with acoustical listening devices for describing the forms and strata of life.

f. Surveying the ocean bottom to determine the effects of bottom topography on current movements and of the interrelationship among the currents themselves.

g. Surveying of marine resources.

h. Conducting acoustics studies while maintaining a "dead ship" condition.

4. OBJECTIVES OF THE SCIENTIFIC RESEARCH SUBMERSIBLE SUPPORT SYSTEM

Since the Submersible System must be transported to the operational area and supported in the area during a mission, a highly dependable Support System is needed. The main objectives of the Support System are to provide accommodation and research facilities, checkout, maintenance, replenishment, and physical handling of the Submersible System. The proposed Support System needs to feature the following capabilities in order to achieve those objectives:

a. Cruising range of 3000 miles.

b. Accommodation for 20 scientists and 3 members of the crew of the Submersible System.

c. Modern precision navigation system to locate the dive site.

d. Precise position determination capability to give three-dimensional fix of the Submersible System relative to bottom markers.

e. Roll stabilization.

f. Data processing, reduction and storage.

g. Library and reading facilities.

h. Photo processing facilities.

i. Scientific "dry" and "wet" laboratory spaces.

j. Decompression facility.

k. Ability to support oceanographic measurements including bottom covering, sub-bottom acoustic profiling and echo sounding.

l. Vehicle handling system and replenishment facilities.

m. Shops, spare parts and other maintenance requirements.

5. THE PROBLEM AND NAVY RELEVANCE

By increasing detail knowledge of the sea, its content and its floor, the naval laboratories make important contributions to effective fleet operations. This is particularly true of acoustics work and its application to submarine operations. The SRS-20,000 system would provide the means to conduct experiments and obtain information not now attainable.

6. THE SUPPORT SHIP CONCEPT DEVELOPMENT

A review of current submersible support ships provided some needed information to draw up a tentative set of support ship characteristics, subject to change and refinement at the discretion of the sponsor and users and as a result of more detailed studies.

CHARACTERISTICS

Speed (Maximum)	15 knots
Range	3000 miles
Displacement	2500 tons
Length	200 feet
Beam	50 feet
Draft	9 feet
Dead Weight	500 tons
Shaft Horsepower	3000
Propulsion Machinery	Diesel
Fuel Capacity	300 tons

The SRS-20,000 support ship design parameters depend to a great extent on its mission profile. The system mission requirements established by the sponsor and users during a design review are as follows:

a. SRS-20,000 will operate only in warm and fair weather, sea state 2, with light winds, and visibility not less than 5 miles.

b. SRS-20,000 will be launched, taken aboard, or if towed will be brought alongside in lee, with the support ship rolling at an angle of no more than 5 degrees.

c. Maximum number of dives will be made during daylight hours; however, if night operation is a requirement, adequate lighting shall be provided.

d. The SRS-20,000 support ship will be capable of operations from third, second or first class harbor or port facilities.

e. Primary support commodities will be carried in sufficient quantities to sustain operation of the total system from any base port for six months; secondary support commodities, usually available from third class foreign ports, will be stocked to last two weeks.

f. The support ship will enable the SRS-20,000 to make up to four completed dives each week with no more than one dive per day for a two-week period without returning to base port.

g. The support ship is to be able to make ocean transits with a reasonable number of replenishment stops. Replenishment at sea is not required.

h. The support ship will not have rescue capability in the event the SRS-20,000 becomes disabled while submerged.

i. Comfortable accommodation comparable to those found on board commercial passenger liners shall be provided.

j. The support ship will have adequate facilities to accommodate two ten-person scientific parties comprised of both men and women.

The following facilities are considered minimum requirements on board regardless of the type of support ship selected.

a. Air-conditioned living, dining and working quarters.

b. Roll stabilization.

c. Library, microfilm storage and reproduction.

d. Data processing, reduction, and storage.

e. Photographic laboratory and dark room.

f. Computer and memory storage banks.

g. Instrumentation repair.

h. Conference room.

i. Project command room.

j. Specimen and freezer room.

k. Precision navigation space.

l. Decompression chamber.

m. Machine shop.

n. Administrative offices.

o. Marine biology, geology, and physical oceanography workrooms.

p. Lounge and recreational spaces.

The following facilities are recommended in the weathered area:

a. Weatherproof lockers for experiment staging, radiation materials, and hazardous materials.

b. Recreation space.

c. Helicopter landing deck.

d. SRS-20,000 stowed area if submersible is brought on board.

7. SUPPORT SHIP'S SECONDARY MISSIONS

Other factors worthy of consideration are the additional functions a support ship might perform aside from its primary mission. These include normal oceanographic research, survey, reserve cruise training, Naval Academy floating laboratory, and satellite tracking. These missions could be accomplished with minimum alteration to equipments that normally are provided for scientific research submersible support ship functions. If a piece of equipment for secondary missions is foreseen to require special foundation or some unique type of structure, that requirement could be incorporated in the original support ship design. The operating characteristics of a support ship should meet all of its secondary mission operation requirements. Due to the specialized nature of facilities aboard the SRS-20,000 support ship, there is no possibility of it being employed as any type of combatant, supply or transport vessel without major conversion.

8. DESIGN CRITERIA FOR A SUPPORT SHIP

A tentative set of criteria developed to aid in the selection and design of a support ship includes the following items:

a. A satisfactory work platform in sea state 2.

b. High degree of maneuverability and direction control.

c. Good stability and ability to maintain position in heavy weather within the operational area.

d. Reliable shipboard equipment and machinery.

e. Three thousand mile cruising ranges at a speed of 12 knots.

f. High degree of sound damping.

g. Can withstand 70-knot abeam wind and operate efficiently in 40-knot wind.

h. Moderate weather cruising speed of 12 knots.

i. Maximum sustained speed of 14 knots.

j. Capable of towing SRS-20,000 or removing SRS-20,000 from water by hoisting or dock-type landing.

k. Crane capacity of 5 to 80 tons depending on method of removing SRS 20,000 from water.

l. Displacement under 5000 tons (lightship condition A).

9. CONVERSION OF EXISTING SHIPS TO SUPPORT SHIP

Three classes of existing ships qualify as far as size, meeting a major portion of the support ship criteria, design and overhaul efforts involved in the conversion, are concerned. These ships are the Landing Craft Repair Ship (ARL), Salvage Lifting Ship (ARSD), and Seaplane Tender, Small (AVP). A study was made of each class of ship pertaining to space, stability affected by handling and carrying SRS-20,000 in transit, and modifications required for conversion. Different concepts including their pros and cons for handling the SRS-20,000 were developed and the primary concepts are summarized below.

I. CONVERTED ARL (LANDING CRAFT REPAIR SHIP)

Length	-	328 feet
Beam	-	50 feet
Draft	-	14 feet
Speed	-	12 knots
Light Ship Displacement	-	2220 tons
Full Load Displacement	-	4325 tons

Proposed modifications are as follows (see Figure 1):

a. Stow SRS-20,000 in hold (formerly machine shop).

b. Cut opening on main deck and succeeding decks to provide passage for SRS-20,000 to ship's hold.

c. Provide bridge crane on main deck to hoist SRS-20,000 out of water from either side of support ship.

Advantages

1. Modification to main and succeeding decks not extensive.

2. Rearrangement of main deck for deck opening not extensive.

3. Minimum effort required in handling of SRS-20,000.

4. Good weather and wave protection.

5. Center of gravity of added weight kept low.

6. Ready access to shop area.

Disadvantages

1. New bridge crane design and installation required.

2. Relocation of machine shop required.

II. CONVERTED ARSD (SALVAGE LIFTING SHIP)

Length	- 225 feet
Beam	- 35 feet
Draft	- 10 feet
Speed	- 13 knots
Light Ship Displacement	- 1050 tons
Full Load Displacement	- 1280 tons

Proposed modifications are as follows (see Figure 2):

a. Remove existing heavy lifting gear at bow and install a traveling crane capable of lifting SRS-20,000 to a position forward of bow.

b. Hoist SRS-20,000 and transfer it either from or onto main deck.

Advantages

1. Large deck area available.

2. Winches available for heavy haul.

3. Small crew required to operate support ship.

4. Existing salvage facilities asset to support ship missions.

5. Decompression chamber already on board.

Disadvantages

1. Limited range (1,000 to 1,500 estimated).

2. SRS-20,000 unprotected from weather.

3. Lifting SRS-20,000 out of water and off deck complicated by support ship's motion even in slightly rough sea.

4. Support Ship's stability adversely affected during recovery and launch operations.

5. Design development required of sophisticated traveling crane.

III. CONVERTED AVP (SEAPLANE TENDER, SMALL)

Length	-	312 feet
Beam	-	41 feet
Draft	-	14 feet
Speed	-	19 knots
Light Ship Displacement	-	1830 tons
Full Load Displacement	-	2800 tons

Proposed modifications are as follows (see Figure 3):

a. Admit SRS-20,000 to support ship through bow door.

b. Lower floodable section of support ship hull bottom to clear bottom of SRS-20,000. Once SRS-20,000 is inside the support ship, close bow door and remove water from floodable hull bottom, thereby making it a servicing platform for SRS-20,000.

Advantages

1. Good weather and wave protection provided for SRS-20,000.

2. Center of gravity of added weight kept low.

3. Support ship's stability not jeopardized.

4. Heavy lifting machinery not required.

Disadvantages

1. Extensive modification to hull bottom and ship's bow required.

2. Installation of pumping machinery required.

3. Difficult for SRS-20,000 to go through bow door during rough sea.

IV. CONVERTED ARD (BS)-20 (USS WHITE SANDS)

The USS WHITE SANDS, support ship for TRIESTE II, could be converted to support SRS-20,000. The SRS-20,000 is considerably smaller and lighter than TRIESTE II in light condition for docking. Removal of stored gasoline and deep sea winch would provide weight compensation for the installation of quarters and desired scientific facilities. At-sea launching and docking capability has already been proved with TRIESTE II. Many of the needed facilities already exist. The conversion would be low cost. The major disadvantage is the necessity for a towing tug and slow transit speed.

10. NEW CONSTRUCTION SUPPORT SHIPS

I. NON-SELF-PROPELLED SUPPORT SHIP (BARGE TYPE)(see Figure 4):

Length	-	202 feet
Beam	-	45 feet
Draft	-	6 feet
Speed	-	6 knots towed
Light Ship Displacement	-	Unknown
Full Ship Displacement	-	1300 tons

Scheme for launching and recovery of SRS-20,000 part of basic design.

Advantages

1. Operating cost lower than self-sufficient ship.

2. Construction cost lower than self-sufficient ship.

3. Good wave protection for SRS-20,000 while in transit.

4. Maintenance cost lower than self-sufficient ship.

5. Smaller complement of personnel to operate support ship.

6. Less vibration due to absence of propulsion machinery.

7. Would not be a commissioned ship.

8. Only small engines required to position ship in vicinity at scene of operation or for short transits.

Disadvantages

1. A tug is required for towing and standby during a mission.

2. Slow transit speed.

3. Poor maneuverability can be expected.

4. Comfort sacrificed in this type of support ship.

II. SELF-SUFFICIENT SUPPORT SHIP (CATAMARAN)(see Figure 5):

Length	- 200 feet
Beam	- 72 feet
Draft	- 15 feet
Speed	- 15 knots
Light Ship Displacement	- Unknown
Full Load Displacement	- 2500 tons

Advantages

1. Methods for launching and recovery of SRS-20,000 in the most efficient manner incorporated in the design and proved in operation of ASR's with DSRV.

2. Shipboard arrangement made to suit scientific and oceanographic endeavors.

3. Users can exercise greater freedom in deciding space arrangement, compartment size, speed and range of support ship.

4. High morale of passengers and crew likely aboard new ship.

5. Design of ship and submersible would proceed jointly as an integrated system.

Disadvantages

1. Initial cost.

2. Longer design and construction time.

3. More time required for sea trials.

The catamaran hull form was selected for the following reasons:

a. The handling of the SRS-20,000 during launch and recovery would be accomplished at approximately amidships where the vertical motion due to roll and pitch would be virtually eliminated, and good protection from waves would be realized.

b. The good roll damping inherent in this hull form would assist greatly in all over-the-side experiments as well as providing a more comfortable and stable work platform.

c. The low speed maneuverability required during SRS-20,000 launch and recovery operations would be enhanced by the wide separation of the propellers.

d. The hull form would provide more deck space than a single hull ship of equal displacement.

11. CONCLUSIONS OF THE SUPPORT SHIP STUDY

Although there is a great disparity in costs between conversion and new construction, the additional activation and repair costs involved in conversion will no doubt be significant. These latter costs have not been estimated. Therefore, final selection of a support ship would depend primarily on economics and budgetary considerations.

12. THE SUBMERSIBLE CONCEPT DEVELOPMENT AND STUDIES

Studies of the submersible focused on the broad concepts of vehicle configurations which would be compatible with the objectives cited initially and the Support Systems defined above. Also, materials, components, and sub-systems were reviewed against the state-of-the-art and mission requirements. Finally, a family of parent design models was developed. These parent designs can now be adjusted as required to suit final selections of the basic material or sub-system elements which make up the vehicle. These selections will finally be primarily governed by economics and future development, plus more detailed studies of reliability, maintainability and similar life-cycle considerations, all judged against the mission requirements.

There are two basic approaches in the parent designs. One is primarily a vehicle which has acceptable surface characteristics, suitable for a towed vehicle system or one which stays in the water throughout a dive series. The second group are primarily submersibles and are intended to be removed from the water between each dive. Characteristics are the same except as indicated in the detail discussions.

13. SECONDARY MISSIONS

No secondary missions have been listed for the purposes of this study. However, a capability such as this would have certainly been called upon during the search for the lost weapon off Palomares, or the THRESHER and SCORPION searches. The deep depth capability, significant payload capacity and ocean-going capability would assuredly make this system much desired in such events.

14. FUNDAMENTAL DESIGN CONSIDERATIONS FOR VERY DEEP SUBMERGENCE VEHICLES

I. THE SUBMERSIBLE SYSTEM

a. The major elements of a deep submergence vehicle are:

1. Pressure hull

2. External fairings and basic skeletal structure

3. Supplementary buoyancy

4. Trim and buoyancy control system

5. Maneuvering system

6. Propulsion system

7. Power source and distribution

8. Instrumentation and controls

9. Payload and payload-related equipment/systems

b. These elemts and how they are arranged determine the weight and displacement of the vehicle. Therefore, since weight and displacement strongly influence the support system and vehicle maneuverability, considerable attention must be focused on these elements in order to develop an effective design.

c. These elements, their performance capabilities, how they are arranged and how they interact, must be matched with the operating sequences which most effectively carry out the typical mission profiles required.

d. The durability, reliability and maintainability of these elements will determine life-cycle costs, life duration, percentage of time the system is capable of performing its mission and the ease or difficulty involved in maintaining the system in operating condition - all measures of system effectiveness.

e. Finally, the submersible system will be the result of the synthesis of all the decisions made about all these considerations. The most successful system design will be the one in which that synthesis results in a system which most effectively performs the real missions for the amount of money expended.

f. Based on the mission profiles defined by the sponsor and potential users, mission effectiveness factors are as follows:

1. Small vehicle size to facilitate between-dive docking in or on the support ship for vehicle servicing, replenishing and checkout and for payload changes, servicing and checkout.

2. Small vehicle size and optimum form for good submerged maneuvering in mid-water and near the bottom.

3. Simplicity and reliability of operation to maximize the percentage of time the vehicle can dive.

4. Ease of maintainability to minimize the effort, cost and time required for maintenance.

5. Sphere arrangement and equippage to provide maximum scientist visibility, comfort, observation and attention to experiments or data acquisition.

6. Minimum magnetic, electromagnetic and acoustic signature during "dead ship" conditions.

7. Flexibility and adaptability of payload mounting, electrical-electronic support features and vehicle buoyancy control.

II. THE FUNDAMENTAL INFLUENCES OF VEHICLE SIZE ON OVERALL SYSTEM PERFORMANCE

Vehicle size influences every aspect of overall system performance. For example, it affects:

Vehicle handling equipment on support ship.
Overall displacement and stability of the support ship.
Vehicle maneuverability.
Structural weight.
Power required for propulsion.
Power required for maneuvering.
Size of trim system.
Size of buoyancy control system.
Size of power source.
Size of emergency recovery system.
Size of hoisting or docking gear.
Size of mooring and towing gear.
Vulnerability to underwater collisions (due to mass and inertia).

It can be seen from this that there is a weight/displacement spiral. Starting from a given design point, any increase in the weight to displacement ratio or total weight of any unit immediately causes an increase in overall size. This requires an increase in power, weight of structure, trim system, buoyancy control system, etc., etc., etc. The reverse is also true. Therefore, to achieve a small size vehicle for operations to 20,000 feet requires a ruthless attack on each vehicle system and element to ensure that it is not unnecessarily heavy or that its weight to displacement ratio is not unnecessarily high.

It is plain then that the largest and heaviest systems or elements deserve special attention from the standpoint of weight and displacement because of their significant affect on overall size.

III. THE IMPORTANCE OF MATERIAL SELECTION AND THE DESIGN OF MAJOR VEHICLE SYSTEMS AND ELEMENTS ON SIZE

A primary relationship affecting size in a very deep submersible is the weight to displacement ratio of the items of which the submersible is constituted. In a shallow submersible the displacement of the pressure structure exceeds its own weight and there is, therefore, surplus buoyancy available to carry the excess weight of batteries, motors, etc. This is not yet true for the very deep submersibles. For the resent and the immediate future, titanium and very high strength steels represent the state-of-the-art and we must be content with a pressure structure for 20,000 feet which weighs more than it displaces. This, of course, means that we must provide supplementary buoyancy to overcome this excess weight, as well as any excess weights of batteries, motors, etc.

A second important element is the vehicle hull external fairing and basic skeletal structure. The larger the vehicle, the more significant this item becomes. Here again, material selection is of the utmost importance, remembering that supplementary suoyancy must be provided for any excess of weight over displacement. The following table of material net weights in water is of great importance in understanding this point.

MAT'L	DRY WT. (GR. PER CC)	NET WT IN SEAWATER (GR. PER CC)
Steel	7.87	6.85
Alum	2.70	1.68
Titanium	4.50	3.48
GRP	1.97	0.95
"Plyglas"	1.02	0.00

Upon close examination it can be seen that 85% of the dry weight of steel must be provided with supplementary buoyancy. For aluminum it is 38%; for "Plyglas" it is zero. Obviously, one must also consider the quantity of material required to provide a satisfactory structure and that is a function of its strength. Just as is the case with the pressure structure, the final selection of vehicle hull material should be strongly influenced by the relationship of density to strength. At the present time aluminum is a good material from this standpoint, is relatively inexpensive to fabricate and is a reliable material with respect to predicted properties. "Plyglas" is ideal from the density to strength consideration since it would not require any supplementary buoyancy, but is costly to fabricate, not as readily adaptable to future changes and its long term endurance under high pressure is yet to be determined.

By similar analysis, each major vehicle element and system can be reviewed and materials selected for their construction. Then the amount of supplementary buoyancy required for each element and system can be established by determining the excess of their weights over their submerged displacements.

Vehicles planned to operate at 20,000 feet in the immediate future will require supplementary buoyancy in fairly large quantities unless they carry no payload, minimal crew and are of very limited endurance and capability. For the SRS-20,000, which is planned for 3 people, 5000 pound payload and other specified performance characteristics, supplementary buoyancy will make up much of the vehicle's displacement. Therefore, it is doubly important to hold down excess weight of pressure hull, vehicle hull and fairing and system weights. In addition, the density and compressibility of the buoyancy material itself is of great importance. Syntactic foam is the most likely candidate for the near future. Density determines how much volume of foam is required to provide the needed supplementary buoyancy. Figure 6 indicates how overall vehicle displacement would vary if foam density changed from 44 pounds per foot^3 to 32 pounds per foot^3. Not only does low density foam reduce submerged displacement and size but also reduces its dry weight, see Figure 7. The reduction in volume of foam is in direct proportion to the decrease in density and the weight reduction results from both the reduced volume and the decrease in the weight of the foam that remains.

Foam with a bulk modulus equal to that of sea water would essentially eliminate any major buoyancy control system except for that required for payload changes and fine control. Ascent and descent and emergency ascent systems would be required in any case but would be of minimum size in the event that foam with this property is available.

15. VEHICLE CONFIGURATION CONCEPTS SIZE SUMMARIES AND GENERAL ARRANGEMENTS

Form concepts are the product of studies of the interrelationship of size (beam, draft, and length), arrangement, weight, speed, resistance (forward and sideways), freeboard, and stability. The forms investigated include the following:

1. Circular cross-section with a shipshaped bow for surfaced towing.

2. Body of revolution, circular cross-section with a streamlined bow profile (may be used for short distance towing) for improved submerged performance and elliptical cross-section with a streamlined bow to reduce resistance to rotation in the horizontal plane with small sacrifice in ahead resistance.

The afterbody of all the above forms is tapered in plan and elevation to provide an unobstructed flow of water into the main propeller mounted at the submersible's stern extremity, and to reduce resistance ahead and sideways.

Summaries are tabulated below. The float structure with a shipshaped bow is to carry a HY-120 steel sphere; the other two forms are to carry a titanium sphere. The inside diameter of each sphere is 7'-0".

SUBMERSIBLE FORMS

	(1) Shipshaped Bow (HY-120 Sphere) 10'-0" Dia.	(2) Streamlined Bow (Titanium Sphere) 9'-6" Dia.	(3) Streamlined Bow 6.9'x13.1' Ellipse
Overall Length Ft.	48'-0"	40'-0"	40'-0"
Ballast Water (Salt)	16,000	9,000	9,000
Foam (40#/ft^3) lbs.	77,760	53,720	53,720
Shot (Steel) lbs	3,200	3,200	3,200
Shipping Weight (Min.) lbs	149,134	109,490	109,490
Lifting Weight (Norm.) lbs	163,564*	123,405	123,405
Displ'm't (surfaced) lbs	174,478	134,025	134,025
Displ'm't (submerged) lbs	190,484	143,025	143,025
Payload lbs	5,000 lb (dry)	5,000 lb (dry)	5,000 (dry)
Sphere material	HY-120	Titanium(110,000yld)	Titanium(110,000 yld)
Sphere Weight lbs	30,600	18,100	18,100
Margin	0	0	0

*Without crew, shot, or payload = 154,884

The reduction in the quantity of foam where a titanium sphere is installed is quite apparent. The saving of 24,000 lbs of foam at 10 dollars a pound installed, would help to offset the difference in cost for a titanium sphere.

Syntactic foam with a density of 36 pounds per cubic foot would allow a reduction of approximately 20,000 pounds in the above submersibles.

Detail weight summaries for a vehicle using an existing HY-120 steel sphere and for a vehicle using a titanium sphere are as follows:

WEIGHT	DISPLACEMENT (POUNDS)	
30,600	15,360	Sphere (120,000 yield steel)
12,450	4,725	Structure Alum Alloy
15,340	11,533	Prop/elec (incl comp. fluid) 112.7 ft^3
1,700	400	Elex (external only)
4,230	1,800	Aux. systems
4,050	------	Outfit/ftgs/habitability (incl sphere internals)
5,748	------	Comp. fluid & hyd. oil
480	------	Crew
5,000	1,850	Payload
3,000	3,000	Buoy. control tank (Ti) 47 ft^3
3,200	480	Shot
85,798	39,148	
-39,148		
46,650	Supplementary Buoy. Req'd(1944 ft^3)	
85,798	39,148	
77,760	124,416	Syn. foam at 40 P.C.F.

$\frac{46650}{24} = 1944\ ft^3$

$1944 \times 40 = 77760$

1944×64: 7776, 11664, 124416

163,558	163,564	=	Launching Wt. 72.8 tons	163564
6,720	6,720		Scientific well water	- 3680
4,200	4,200		Free flood areas	159884
9,000	9,000		Aft mbt[NOTE: Buoy. contr. tk. is]	- 5000
7,000	7,000		Fwd mbt[blowable & adds 3000 lb]	154884
190,478	190,484		[buoyancy on surfacing.]	
6			Shot to balance	
190,484	190,484	=	Submerged displacement 85.0 tons	2975 ft^3
			48'x10' dia, or 48'x7'x14'x.80Cp	
163,562	5,000		Payload	
-14,428	3,200		Shot	
149,134	480		Crew	
Shipping	5,748		Comp. fluid	
Weight	14,428		Portable weights	
=66.6 tons				
163,558				
6,720				
4,200				
174,478	= Surface Displacement = 77 tons			

NOTE: A submersible which is serviced in the water between dives would require more main ballast tank capacity to provide more freeboard. Also, hull form should be circular to increase freeboard and improve towing stability. Such a vehicle should have a fairwater to protect personnel and access hatch to sphere. The scientific well should be fitted with covers so it could be blown dry for long distance towing. If the submersible is taken out of the water for servicing, main ballast capacity could be reduced and structural weight would be less, making the submersible about 83.3 tons submerged displacement and 46'-0" long.

WEIGHT	DISPLACEMENT (POUNDS)				
18,100	15,360	Sphere Ti 110,000 yield			
9,350	3,553	Struct, Alum Alloy			
15,340	11,012	Prop/elec (incl. comp fl 103 ft^3)			
1,700	400	Elex (external only)			
4,230	1,800	Aux. systems			
4,050	-------	Outfit/ftgs/habitability (incl sphere internals)			
5,235	-------	Comp. & Hyd. Fluid			
480	-------	Crew			
5,000	1,850	Payload			
3,000	3,000	Buoy. control tank (Ti) 43 ft^3			
3,200	480	Shot	1,343 ft^3	of 40#	Syn. Foam
69,685	37,455		24/32,230	1343	1343
-37,455			24	40	64
32,230	= Supplementary Buoyancy Req'd		82	53,720	5372
69.685	37,455		72		8058
53,720	85,952	Syn Foam	103		85952
123,405	= 123,407	= Launching Wt (55 tons)	96		
			70		
6,720	6,720	Scientific Well			
3,900	3,900	Free flood water			
6,000	6,000	Aft mbt			
3,000	3,000	Fwd mbt			
143,025	143,027	Submerged Displ (63.8 tons) 2234.8 ft^3 40'x9.5'dia			
		or 40'x6.8'x13.1'x.79Cp	.79Cp		
123,405			5000 payload		
6,720			3200 shot		
3,900			480 crew		
134,025	= Surface Displacement (59.8 tons)		5235 comp fluid		
			13915		
123,405					
-13,915					
109,490	= Shipping Wt (48.8 tons)				

Volume Check	
Sphere	240
Syn. Foam	1343
Comp Fl.	103
Buoy. Tank	47
Water	306.5
Struct.	55.5
Aux. Sys.	28.1
Elex.	6.2
Prop/Elec	67.5
Payload	28.7
Shot	7.5
	2233.0

NOTE: THESE WEIGHT SUMMARIES DO NOT INCLUDE ANY MARGIN.

Calculations of the resistance to a one knot side current, normal to the axis of the submersible, were made for circular and elliptical hulls of identical length (50'-0") and displacement.

	CIRCULAR HULL (10'-0" DIA)	ELLIPTICAL HULL (7'x14')
Residual Resistance (hull)	1070 lb	435 lb
Residual Resistance (Appendages)	320 lb	320 lb
Frictional Resistance	11 lb	13 lb
Effective Horsepower (EHP)	4.5	2.38
Shaft Horsepower (EHP/0.60)	7.10	3.95

Evaluation of circular versus elliptical shaped hull forms for this mission shows much in favor of the latter. However, the elliptical hull's initial metacentric height and freeboard will normally be less, and these parameters and their effects must receive special attention lest the advantages vanish because of stability ballast and increased ballast tank size.

Arrangements

The basic arrangement was dictated by users' requirements (Mission Profile) and the need for hydrostatic balance. Information was supplied by NEL letter of 7 October 1966, which combined USNUSL and NEL requirements. The SRS-20,000 will be on even keel with a 5,000 lb. payload located at about 12% of its length aft of the forward perpendicular. The understanding was that only a small proportion of this payload would be released to the ocean floor and the arrangement was predicated on this requirement. The buoyancy control system assumes a 2,000 pound change.

The arrangement concept is based on the mission effectiveness factors discussed under "Fundamental Design Considerations for Very Deep Submergence Vehicles".

The sphere is low to maximize visibility and is positioned aft of the scientific well and bow-mounted devices. The scientific well and light weight manipulator are positioned for best observation and so that the manipulator can reach experiments mounted in or under the well, or on the ocean floor, but cannot accidentally collide with sphere viewports. Lights, cameras, etc., are in the forward work area although no attempt has been made to pick specific locations at this stage of the study.

All batteries, pumps, compensators and electrical panels are concentrated in an electrical equipment space and main ballast tank. This arrangement provides maximum ease of checkout and maintenance, maximum protection for cable runs, efficient use of structural material, minimizes quantity and weight of cabling and piping and concentrates the heaviest mass near the center of the vehicle to enhance maneuverability. Thrustors and trim tanks are at the ends of the vehicle to obtain the greatest possible turning moment with the least expenditure of energy.

The inverted "Y" tail appendages provide dynamic stability in the horizontal and vertical planes during cruise and will be stabilizing during ascent phases, particularly emergency ascent. However, they provide small resistance to lateral or rotational maneuvering at zero forward speed. With the elliptical hull cross section and faired sphere near midships, the hull form itself also provides a minimum of resistance to rotation around the vertical axis.

Thus, the combined low moment of inertia resulting from placement of masses and the basic form of the vehicle greatly enhance the maneuverability at slow or zero forward speeds.

The concentration of heavy weights also lends itself to a very efficient structural design. The arrangement allows for a central strong frame system which holds the sphere and other weights, provides for a good hoisting attachment, a docking or grounding system, bulkheads capable of withstanding main ballast tank blow pressures and an attachment for the heavy lift manipulator.

The arrangement also allows a high packing factor, i.e., the percentage of total volume defined by the vehicle form which is occupied by equipment or syntactic foam rather than by free water. This also reduces overall vehicle size and structural weight.

The advantages of this "central core" concept are so important that they were applied to all the schemes developed.

Three arrangement conceptual drawings are included in the appendix. One drawing shows a 45 ft. long, 10 ft. diameter submersible of the non-towable hull form, (see Figure 8). This size vehicle could carry a steel sphere. A second shows a 48 foot long submersible of a towable hull form with a shipshaped bow and a HY-120 steel sphere, (see Figure 9). It should be noted that the towable hull form has much more available volume in the bow section for flotation material. The third shows the recommended 42 ft. long elliptical submersible of minimum size for maximized mission performance, (see Figure 10). It would be fitted with a titanium sphere.

Several methods for unloading the pressure sphere from the float structure were considered. Removal of the pressure sphere from the topside of the float structure was decided best. With the pressure sphere strapped to an eight-foot upper-half section of the float structure, the entire assembly could then be lowered into position and secured by bolts.

16. SUBMERSIBLE BUOYANCY CONTROL AND TRIM

As discussed in Section 14, the vehicle elements needed to perform the functions required are first defined and estimates of the weights and displacements of these elements are made These weights minus displacements gives the wet weights of the total elements which make up the desired submersible. To this must be added sufficient quantities of supplementary buoyancy material so that total weight and total buoyancy are equal. However, the submersible must be in balance, not only near the surface, but also throughout the mission profile and under the control of the pilot.

Where the submersible elements compress less than sea water, buoyancy increases with depth and vice versa. By selecting a proper mix of quantities of buoyancy materials with differing compressibility, e.g., syntactic foam and silicone fluid, we can create a submersible which essentially is automatically self-compensating for a given set of circumstances, (average surface temperature, average sea water density at the bottom, measured compressibility of fluid and syntactic foam actually used, average wet weight of payload, etc.). Even the widest range of conditions is entirely manageable. For example:

Assume: Seawater density at 20,000 ft = 65.6 pounds/cubic ft.
Sphere compression at 20,000 ft = 2 cubic ft. reduction
Syntactic foam compression = 2.12%

Then: 238x65.6-240x64 = 252 lbs buoyant excess - sphere
1343x(100-2.12)x65.6-1343x64 = 279 lbs buoyant excess-syn. foam
193.5x65.6-64 = 319.6 lbs buoyant excess-rigid mat'ls (struct etc.)
Total 850.6 lbs buoyant excess

However, compensating fluid compresses about 11% from combined temperature and pressure effects when starting in cold weather and 14.2% when starting in hot weather.

And: 103 ft^3 at 11% compression = 745 lbs weight excess (cold weather)
103 ft^3 at 14.2% compression =960 lbs weight excess (hot weather)
850.6-745 = 105.6 lbs buoyant starting in cold weather
960-850.6 = 109.4 lbs heavy starting in hot weather
Average deviation = ± 107 pounds.

Thus, the submersible will essentially be in balance throughout the water column ($\frac{107\text{lbs}}{20000}$= 0.005 lbs change in one foot of vertical travel.)

The submersible could therefore change depth significantly with propulsion power alone.

NOTE. "Rigid mat'ls" include the following:

Structure	55.5 ft^3
Auxiliary Sys.	28.1
Electronics	6.2
Prop/Elec	67.5
Payload	28.7
Shot	7.5
Total	193.5

Once this basically self-compensating submersible is achieved, we still must provide to the pilot the ability to adjust buoyancy and/or weight to accommodate deviations from the average set of circumstances. In addition, we must provide to him the ability to precisely modify buoyancy and/or weight as necessary in order to execute the mission profile. For SRS-20,000 this includes hovering at five points during the descent, setting a 2000 pound payload on the bottom, hovering near the bottom, picking up the 2000 pound payload off the bottom and returning to the surface.

What would be most desirable for this submersible is a system that is reversible. But, reliable pumps for the pressures involved do not exist; the hydraulic system would be compensated by sea water, eliminating any schemes for changing displacement. Electric heating to change the volume of compensating fluid was suggested, but this would be very slow, inefficient and extremely limited because of the nearly infinite heat sink which the ocean is.

If the mission profile is executed entirely by releases of buoyancy and weight, requirements are as follows:

EVENT	DECREASE (LBS.) Buoyancy	Weight
Start descent	200	
Stop		200
Start	200	
Stop		200
Start	200	
Stop		200
Start	200	
Stop		200
Start	200	
Stop		200
Set down 2000 lbs	2000	
Pick up 2000 lbs		2000
Start ascent		200
	3000	3200

Such a system would require carrying 11,730 lbs (230 ft^3) of fluid at 51 lbs/cubic foot, which could be released and replaced with sea water in order for the submersible to become 3000 lbs heavier plus the carrying of 3200 lbs of shot which could be released in order for the submersible to become lighter. 230 ft^3 would require a 10 ft. diameter vehicle to be 3 ft. longer.

If the mission profile is executed by increases and decreases of weight, however, requirements are as follows:

EVENT	WEIGHT +increase	-decrease	NET CHANGE
Start descent	200		200
Stop		200	0
Start	200		200
Stop		200	0
Start	200		200
Stop		200	0
Start	200		200
Stop		200	0
Start	200		200
Stop		200	0
Set down 2000 lbs	2000		2000
Pick up 2000 lbs		2000	0
Start ascent		200	-200
TOTAL	+3000	-3200	-200*

*This illustrates the desirability of a pumping system which would be reversible.

A pressure proof sphere, 4.5 ft. in diameter, fitted with a control valve to allow water to enter on command, would allow an increase in weight of 3130 lbs. at depth when full. With 3200 lbs. of shot the full mission profile could be executed by increases and decreases in weight. Such a sphere would weigh about 3000 lbs if titanium and up to 4000 lbs. if steel. Thus if sufficient syntactic foam is built into the vehicle initially to carry this added 3200 pound variable load, (in addition to the permanent tank and shot hardware of course) we could execute the entire mission profile starting with a full shot load and empty tank, ending with a full tank and empty shot wells. Upon surfacing, the tank could be blown dry and any remaining shot residue could be dropped which would provide an additional buoyancy (equivalent to main ballast tank capacity) of 3200 pounds.

The tank inlet valve and shot release valves would be very small to provide a truly fine control in order to satisfy the "dead ship" hovering requirements. The tank and shot stowage would be as close as possible to the longitudinal center of buoyancy and gravity to minimize trim angle changes during the evolutions.

This system greatly reduces vehicle size and enhances mission effectiveness and is therefore recommended. In the event reliable pumps are developed in the future by the DSSV or DOT program, one could be readily adopted to the existing tank and would give that much more flexibility of operator choice.

A special design valve would have to be selected, or developed, and thoroughly tested for this service. However, such pressures are now used in hydrostatic test facilities for which a whole family of piping fittings and valves have been developed. Also, high pressure air flasks have been used successfully in TRIESTE where remotely operated valves have reliably sealed the line between the air flasks and access trunk.

In summary, the submersible would be constituted of materials which make it automatically stay essentially in buoyancy and weight balance throughout the water column. This would allow "steering" by propulsion power/thrusters for following the bottom contour, hovering and significantly changing depth by propulsion power alone so as to simplify operation of the submersible. Secondly, precise buoyancy and weight balance control is provided to the pilot by taking on sea water or releasing shot. This provides the pilot the capability to adjust the weight to precisely match the buoyancy, to use weight excess or buoyancy excess to move vertically, to hover at any depth with a "dead ship," and to set down or pick up materials on the ocean floor.

Fore and aft trim control would be accomplished by pumping mercury between tanks located at the bow and stern. The system would be capable of trimming the submersible plus or minus 15°. The weight of mercury required is dependent on the distance between mercury reservoirs, weight of submersible and initial metacentric height. For maximum initial metacentric height of 6" and a lever of 35 feet, about 800 lbs. would be carried in each reservoir for the size of submersibles developed. Half of this amount (400 lbs.) would be required for 3". Initial metacentric height should lie within this range.

17. MATERIALS

The weight of the pressure sphere and float structure is so related to the ultimate size of the submersible and cost of flotation material that considerable effort was expended to define their interrelations in this design study.

The pressure sphere is the greatest single item of weight in the SRS-20,000. A comparison of various materials that could be used in its fabrication was made for determining trade-off parameters. The materials compared were titanium, HY-120 and HY-180 steel. Titanium is clearly the most desirable material, but is costly. HY-180 steel would also be a good choice at present. HY-120 steel would be a very poor choice from an economic standpoint, except for the fact that a HY-120 steel sphere is already designed. The cost of flotation material to support the extra weight of HY-120 would amount to $240,000, and the length of a 10-foot diameter hull form would have to be increased 8 feet in order to accommodate the additional volume of foam required.

The first titanium sphere is under development under the Deep Ocean Technology Program for the ALVIN/AUTEC vehicles. As previously noted, the increased cost for a titanium sphere will be offset by the reduction in flotation material. Detailed cost information and production requirements are yet to be confirmed by the DOT program.

HY-180 steel is at present an acceptable pressure sphere material. Detailed information on forging and machining processes and their related costs have not been obtained.

Materials for the float structure were studied in their relation to cost, durability, and weight. A hypothetical study was made on the strength to weight and cost to weight ratios of several materials. These include glass-reinforced plastic (GRP), aluminum alloy, titanium, and HY-80 steel. This study showed that out of water, and by the strength to weight criteria, titanium is favored slightly over GRP and aluminum, and considerably superior to HY-80 steel. When submerged in water, the criteria indicated GRP to be the best, aluminum a close second, titanium third, and HY-80 steel a poor last. This study showed that only aluminum and GRP or a combination of the two should be considered. The cost for fabrication favored aluminum over the other materials. The risk of delamination of GRP under extreme pressure prevented recommending its use except for nonstructural fairings.

A basic float structure design was developed for a 10-foot diameter vehicle section of 5456 aluminum alloy. Shell plating is 3/16 inch thick, except in way of ballast tanks where the thickness is 1/4 inch. The shell is stiffened longitudinally between bulkheads. These longitudinals are 3/8-inch flat bars welded to the shell, and spaced at 15° intervals around the perimeter. The bulkheads forming the boundaries of main ballast tank battery space, bulkheads forward of sphere, bulkheads bounding the forward and aft ballast tanks are stiffened 1/4-inch plates. The float structure was designed to withstand 500 pounds per square foot hydrodynamic loads, and the ballast tanks were designed for 10 psi blow pressure.

18. PROPULSION

The SRS-20,000 should have a top speed of two knots and a normal operating speed of one knot provided by the main propulsion system. A secondary propulsion system would be used for turning, hovering, and trim.

The following propulsion systems were studied.

One proposal used rigidly mounted electric motors enclosed in tubular shrouds; two for vertical, two for lateral, and one main motor for fore and aft motion. The vertical and lateral motors would be operated either to create a couple for turning the vehicle or in unison for translation. This system would offer good maneuverability, although some combined lateral and vertical movement would be difficult to control. A total of five motors would be required, some of which would be used only occasionally. This would make the total weight, cost and complexity of the system high, even though the components required for such a system were state-of-the-art.

A second system studied was one in which the main propulsion motor was mounted at the stern on gimbals and directed by small 1/4 horsepower motors. Two fixed auxiliary motors mounted in tubes in the bow would propel the bow vertically and horizontally. The gimbals would enable the main propulsion motor to produce a thrust in any direction within one hemisphere. A feasibility study of this approach proved it to be worthy of further investigation.

The feasibility of using hydraulically driven motors powered by a large central electric motor and pump was also being studied. Such a system would be approximately 20% less efficient than an all electric system, but would offer a 15%-30% weight savings. It would also offer the advantage of having only one electric motor which could be located in a convenient, protected area. This feature would increase reliability and safety. While this method of propulsion would require some development, it is within the state-of-the-art and warrants further investigation.

There are many deep submersible vehicle equipments for which a hydraulic system would be best adapted. Just as in existing submarines remote operation of ballast tank vent and flood valves, ship control operations and others are desirable. Manipulators require hydraulic operation in order to obtain the required power and force in small hardware. Hydraulic power could also be used to steer the main propulsion motor drive the propellers, retract instrumentation too delicate for surface water conditions, jettison equipment, operate mercury trim system valves and similar operations.

Hydraulic systems are inherently reliable and tolerant to the sea water environment if adequate care is given to their design. Experience with ALVIN and CURV shows they can be quite successful in medium depth submergence vehicles. Experience with TRIESTE II manipulator shows the same for deeper depths.

In conclusion, it was recommended that a detailed investigation of the fixed thrustor and main propulsion motors plus fixed forward thrustors and gimbaled stern propulsion motors be made. Also, studies of both hydraulic and electric systems should be made. Studies had indicated that a gimbaled system for the main motor was feasible and would not only give good maneuverability, but would be relatively light weight, fairly compact, and efficient. Work done on DSRV, DSSV, DOT Program and other developmental vehicle propulsion systems should be monitored for applicability.

19. ELECTRICAL PROPULSION SYSTEMS

As far as the ultimate system is concerned, considering only weight and speed control regardless of cost, the A.C. squirrel cage induction motor employing a solid state three-phase variable frequency-variable voltage inverter is the most desirable. However, one should consider the high reliability, based on past experience, of the single speed shunt wound D.C. motor, and the Nadyene brushless D.C. motor which shows great promise.

The three basic types of D.C. motors investigated were the series motor, the compound motor and the shunt motor.

The series motor has a high starting torque and is generally used in applications where the motor must start under load. This application does not fit the needs of a propulsion motor or thrustor for a small submersible since a propeller is lightly loaded until it begins turning over. Even under conditions of plug reversing, the only load that must be overcome is the inertia of the propeller. The torque varies as the square of the current, hence as the speed increases due to increasing back electromotive force, the current drops and the torque is reduced.

The compound motor may be divided into two subtypes. The cumulative compound motor is principally used where sudden heavy loads are placed upon the motor. The differential compound motor is principally used where sudden loads are placed upon a motor that must maintain a very constant speed. Neither of these types of motors offer any particular advantage as a submersible propulsion motor.

The shunt wound direct current motor will start with a small load. As a load is added to the motor, it will slow down slightly, but the shunt motor is considered a relatively constant speed motor. This type of motor has been used as the propulsion motor on the TRIESTE II for several years requiring very little maintenance. The shunt motor is the simplest D.C. motor in construction and has the most desirable characteristics for a propulsion motor.

Three methods of speed control are (1) vary the armature voltage, (2) vary the field strength, and (3) pulse the motor with varying duration pulses.

Varying the voltage across the armature terminals would require a large dropping resistor in series with the armature which could have incremental steps to short out. This method of speed control is highly inefficient since the motor is operated at low speed most of the time which would necessitate a large voltage drop across he resistor. The heat generated in obtaining the large voltage drop would be dissipated to the surroundings.

The second method of speed control is by varying the strength of the magnetic field. Since the field takes a small amount of current compared to the armature current, the power loss dissipated in this method is relatively small. The motor runs faster when the field is weakened dropping the back end and allowing more current to flow through the armature circuit. As the field becomes weaker, the torque decreases. This is an ironic paradox; the torque of the motor decreases as the speed of the motor increases while the torque required for the load increases.

The third method of speed control is obtained by varying the duration of pulsating direct current. This will cause the motor to heat somewhat because of the continuous inrush currents. However, this should be of little consequence since the motor would be submerged in an infinite heat sink. This type of speed control would be required to use solid state devices which would have to be immersed in an oil bath and exposed to the environmental pressure. The J.C. Carter Company has built a direct current pulsating device.

Another type of D.C. motor is the Nadyene motor which is a brushless D.C. motor.. This unit has the advantage that, should salt water seep into the motor there is no commutator to flood. This motor is a new concept and has much potential. North American - Rockwell Company's Beaver is using these types of motors at present. The motor is built by Lear-Siegler. The speed control unit is supplied by J.C. Carter Company. The bread-boarded control unit that was demonstrated left much to be desired. The motor is extremely small, but has speed of 5,000 rpm, in either direction to develop maximum power and would probably require a reduction gear with increased weight.

The alternating current motors considered were the synchronous, wound rotor and squirrel cage induction motors.

The synchronous motor offers no advantages over the direct current machines in construction and is a single speed machine which, if it falls out of step with the frequency because of overload, must be restarted as an induction motor.

The wound rotor induction motor can vary its speed by connecting variable resistors in the rotor circuit and cause the motor to slip excessively and by this method vary the speed of the motor. Since slip rings are required to make the variable resistor connections, the wound rotor alternating current motor is as vulnerable as the direct current motor should sea water seep into the unit.

The squirrel cage induction motor has the advantage that the current in the rotor is induced; hence, in the event of sea water intrusion, the motor will continue to run. The squirrel cage induction motor has a low starting torque, but it is sufficient to start a propeller load since it must only overcome the inertia of the system.

The method used to vary the speed of a squirrel cage induction motor is by converting the direct current from the battery through an inverter to alternating current of any frequency required to operate the motor by varying the bias of the SCR's. This also varies the voltage which will cause the slip of the motor to vary. J.C. Carter has pressurized solid state inverters to 15,000 psi in oil which have subsequently been used to power motors. No units operated by inverters have been subjected to this magnitude of pressure.

Based on information gathered from Hoover Electric Company, J.C. Carter Company and DOT Reports and assuming a 4-hp unit, the following prices and weights were obtained:

(1) The D.C. shunt motor would weigh 500# and cost $5,000. The variable speed pulsating control would weigh about 50# and cost $15,000 Ducted thrustors would not require variable speed. The price of a non-solid state single speed controller would be about $2,000 and weigh about 200#.

(2) The A.C. motor would weigh about 175# and cost $15,000. The estimated cost of the controller is $20,000 with a weight of 50#. Since the thrustors would not require frequency control, the controller price for these units is estimated at $15,000.

The reliability of the D.C. and A.C. systems with speed control is about a standoff as far as the controller is concerned.

20. PRIMARY POWER SOURCE

The potential primary power sources considered for SRS-20,000 were two types of fuel cells and three batteries. The fuel cells examined were the sodium-amalgam oxygen fuel cell and the hydrogen-oxygen fuel cell. The batteries examined are the Lithium-Chloride battery, the Lead-acid battery and the Silver-zinc battery. The advantages of the Silver-zinc battery make it the obvious choice to meet the circular of requirements.

A sodium-amalgam oxygen fuel cell was studied extensively by the MW Kellog Co. for a 6000 ft. submersible. Prototype units of 8Kw were built and tested for short periods of time. The prototypes revealed that there are numerous engineering problems yet to be solved. The problem areas do not appear to be insurmountable; however, lack of funding brought the program to premature conclusion.

Although the study of the sodium-amalgam oxygen fuel cell was for a 6000 ft. submersible, past experience has indicated that components subjected to greater pressure never get lighter and usually become heavier. The fuel cell examined in this study is of considerably larger capacity than that required for SRS-20,000 since it delivers 100KW @ 300 volts for 5 hours. The dry weight of this fuel cell is 10,000 pounds with a total component volume of 204 cubic feet. The unit completely fueled weighs 17,000 pounds and occupies a volume of 304 cubic feet. No effort was put forth to determine the actual size or cost of this type of cell for this particular application because the current state-of-the-art is such that it is inconceivable that this type of fuel cell would be selected as the power source. The major disadvantages with the sodium-amalgam oxygen fuel cell are:

(1) Sodium is an expensive fuel.

(2) This type of cell requires constant supervision.

(3) The steel plate anode must operate only under gravity forces and therefore must always operate nearly in a vertical position.

Other problems would be cryogenic storage of oxygen and liquid storage (high temperature) of the sodium. Sodium reacts vigorously with water and it is doubtful that storage in the hostile environment of sea water would ever be acceptable.

The hydrogen-oxygen fuel cell shows promise, but because of the high weight of the basic components no advantage is gained unless long endurance periods are required where the weight saving of larger quantities of fuel make this type of cell more attractive. These cells also have the problem of cryogenic storage of oxygen.

The Lithium-Chloride battery is extremely attractive because of its high energy-density. The practical energy capacity is estimated at 330 to 440 watt-hours per kilogram which, compared to the silver-zinc 65 to 130 watt hours per kilogram, would reduce weight of the Lithium-Chloride battery to about one-third the weight of the Silver-zinc battery. The electrolyte is fused Li-Cl at 650°C at 1 atmosphere. The melting point for Lithium is 186°C which is above the temperature to cause a vigorous exothermic reaction should the Lithium come in contact with water. At the present state-of-the-art it is doubtful that Lithium Chloride batteries are a serious contender for the primary power source of a deep submersible.

The foregoing power systems all have shortcomings that eliminate them for SRS-20,000. The next two concepts for the primary power source to be discussed are Lead-acid batteries and Silver-zinc batteries both of which are reliable and are within the "current state-of-the-art." A decision must be based upon the cost effectiveness of these two batteries. This cost effectiveness must not only be based on initial cost but also on the future maintenance of battery. In order to rationally discuss the comparison of cost of the two batteries a power analysis was made based on actual load values of TRIESTE II and the estimated power for special equipment required for SRS-20,000.

The power analysis revealed that the power required for SRS-20,000 is 1200 ampere hours at 120 volts (nominal) and 2400 ampere hours at 24 volts (nominal). A comparison of the important parameters for the two types of batteries showed 14,000 lbs of lead acid vs 4,000 lbs of silver-zinc required.

Silver-zinc batteries have a recovery value of about 35% of the initial cost since the silver can be recovered after the cells have lost their usefulness.

In addition to the cost of procurement of the cells themselves, a battery monitoring system to indicate when to terminate the charge or discharge of the cells would cost about $70,000. This monitoring system is desirable for a lead acid battery and mandatory for the silver-zinc battery. Battery boxes, compensating systems, bubble breakers and potting costs are about equal for either type.

When the cost comparison of lead acid versus silver zinc batteries is made, one also must consider the additional cost of about $250,000 of syntactic foam required to float the lead acid batteries.

The cost of maintenance of the lead-acid battery as compared to the silver-zinc must also be compared. The primary maintenance cost is due to the generation of gas by the batteries during charging and to some extent discharging. The proper charging of lead-acid batteries requires overcharging and therefore excessive gas generation due to electrolysis of the water mixed with the acid. The proper charging of silver-zinc batteries must be very carefully controlled with no overcharging and therefore very little gas production. The adjustment of the electrolyte level of lead-acid batteries must be accomplished 5-10 cycles compared to once per year for silver-zinc. The reduced gas generation has another effect in relation to battery grounds which are very costly to isolate and remove. The gas bubbles carry electrolyte out of the cells and into the compensating fluid. There has been great progress made in minimizing this phenomenon through the use of "bubble breakers" on the tops of the cells but minute traces of electrolyte still escape from the cells and eventually cause battery grounds even if the cell jumpers are completely insulated. Since the silver-zinc battery generates less gas it is less susceptable to electrolyte caused grounds all other conditions being equal. It is very difficult to obtain accurate maintenance cost comparisons, but it is logical that they are considerably less for the silver-zinc.

When all cost factors are considered, the difference between lead-acid and silver-zinc batteries are not so great and the factors favoring the smaller and lighter battery will tend to override the higher initial cost of the silver-zinc.

21. LIFE SUPPORT

System Analysis

The life support system capabilities were set by the life requirements of a 12-hour 3-man mission with a 24-hour emergency reserve. First, the necessary parameters for life and human comfort were defined as: the necessary environmental gases, the absence of toxic gases, temperature control and humidity control. These variables had to be under precise control for the duration of the mission.

1. Physiological Analysis

A detailed study of physiological requirements was made to establish life support system requirements. The following requirements were selected to keep the crew in top mental and physical condition. Some of the values given are listed as both rates and totals. The totals are based on a three-man, twelve-hour mission. Since the physiology of different people varies, these values were given as ranges with the average being mid-range, rather than as specific values.

Oxygen: The oxygen level must be maintained between 20.5% and 21.5% by volume. Consumption of O_2 by people seated and engaged in moderate activity is 0.11 - 0.17 lb/man hr or a mission total of 2.0 - 6.1 lb.

Carbon Dioxide: The CO_2 level must not exceed 1% at any time and must average less than 0.8%. Production of CO_2 by people seated and engaged in moderate activity is 0.12 - 0.19 lb/man hr or a mission total of 4.3 - 6.5 lb.

Humidity: For comfort, relative humidity should be maintained between 30% and 70% depending on the temperature. Expired water is produced at a rate of 0.09 - 0.14 lb/man hr which gives a mission total of 3.2 - 5.0 lb. Perspiration is produced at a rate of 0-0.25 lb/man hr by a seated man engaged in moderate activity. This gives a mission total of 0-9.0 lb for perspiration. The mission total moisture addition is 3.2 to 14.0 lb. excluding any initial bilge water or wet clothing.

Temperature: For maximum comfort of the crew, the temperature should be maintained at 66° - 71° E.T. (ASHRAE effective temperature). To prevent active perspiring, the temperature must be below 78°ET. The heat generated by the crew would be 480 - 860 btu/man hr or a total of 17,300 - 31,000 BTU per mission.

2. Thermal Analysis

To minimize power consumption, it was desirable to achieve a thermal balance between the heat generated within the sphere and the heat dissipated through the sphere to the sea. The sphere could be insulated such that a thermal balance would be maintained for warm waters, making it necessary to heat the sphere in cold waters, or it could be insulated to maintain a balance in cold waters, making it necessary to cool the sphere in warm waters. Since the vehicle would spend the greatest portion of a mission in 40°F water, the most economical procedure would be to insulate for a thermal balance in 28°F water. This would make it necessary only to cool.

The quantity of heat generated within the sphere would vary with the number of occupants, their activity, and the amount of electrical and electronic gear that would be in operation at the time. Moreover, the scrubbing of CO_2 would utilize an exothermic reaction, the heat output of which would also vary, depending on the quantity of CO_2 being absorbed.

3. Additional Considerations

Dehumidification would be required. To provide for crew comfort and to prevent damage and faulty operation of electronic equipment, relative humidity should be less than 70%. Also it would not be unlikely for a crew member to enter the sphere with wet clothes or even for small quantities of water to be splashed in through the hatch. Either of these conditions would place an extra load on the dehumidifier.

Cooling loads in addition to body heat would be the CO_2 scrubber and electronic equipment. It was estimated that an adequate scrubber using lithium hydroxide would produce 450-670 BTU/hr and electronic equipment would produce 1,500-3,500 BTU/hr.

Proposed Systems

For each sub-system of the life support system, several methods of performing the sub-system function were investigated and recommendations made.

1. Oxygen Supply

Four methods of oxygen supply were investigated; they were compressed oxygen, cryogenic storage, potassium superoxide and chlorate candles.

A compressed oxygen supply, consisting of a pressurized container with a regulating device for releasing the gas to the cabin atmosphere, has been well proven in all fields of life support. The supply can be maintained at ambient temperature. Such a system is simple, reliable and was our recommendation.

2. O_2 Sensor Systems

Two methods of regulating the oxygen supply were investigated. One system regulated the supply by sensing the total pressure of the atmosphere and the other regulated the supply by sensing the oxygen partial pressure. The partial pressure sensor was the most logical choice since it would take a direct measurement of the oxygen level in the atmosphere; however, the reliability of the sensor is adversely affected by excess humidity as is the case with most electronic equipment. The total pressure sensor and supply system is less accurate, because of pressure changes due to temperature changes and sphere compression reducing the volume, but more reliable. Further research should be done in the area of O_2 partial pressure sensors and methods of increasing their reliability. A partial pressure sensor could be used in conjunction with a sensitive pressure gage to monitor the cabin pressure for a check. There should be manual over-rides on the automatic sensor and oxygen supply.

3. Carbon Dioxide Removal

Carbon dioxide removal systems were limited to a few chemical systems because of the compact size required of the unit. The four chemicals compared were lithium hydroxide, baralyme, potassium superoxide and sodasorb.

If the humidity within the sphere were kept low enough so that moisture did not seal up the LiOH granules and reduce their absorption capacity, LiOH would be the most efficient CO_2 absorbent of the four. However, if the moisture content of the atmosphere were not maintained at a sufficiently low level, then sodasorb or baralyme would operate more efficiently since moisture has a lesser effect.

4. Temperature and Humidity Control

As a result of heat transfer studies of the sphere, it was decided that with proper insulation a simple cooling system would be sufficient for temperature control. The sphere would be insulated to balance the rate of heat loss in the coldest expected environment with the minimum rate of heat generation in the sphere. Insulated in this way no heating system would ever be required.

The most practical method of removing humidity from the air is to condense it by lowering the temperature. Therefore, we proposed to combine the dehumidification system with the temperature control system. The following is a discussion of the systems considered:

Hull heat exchanger system - The hull heat exchanger system used a twenty square foot heat exchanger which would be bonded directly to the inside of the sphere. In this heat exchanger coolant would circulate directly over the hull and give up heat which it would pick up from the air in an air/coolant heat exchanger. A small variable speed pump would circulate the coolant through the hull/coolant and the air/coolant heat exchanger.

Thermo-electric cooling/heating system - The crew space heat would be absorbed in a thermoelectric heat pump and transferred to the hull and the sea by a closed liquid loop and hull heat exchanger. In the thermoelectric heat exchanger, electric current would be made to flow through a series array of thermocouples. Depending on the sense of the current, a hot or cold junction would be presented as a sink or source to the crew space air. This system would be fairly effective even in warm water although overall efficiency would be lower.

Self-contained refrigeration unit - The use of a freon vapor cycle refrigeration unit was also studied. This system would use a hull heat exchanger to transfer heat and, since freon is toxic, the refrigeration system with the hull heat exchanger and the cabin heat exchanger would use a water-glycol mixture for the transfer media instead of freon. This system would be more efficient than the thermoelectric unit and could also cool in warm water. The unit would be quite large and consume considerable power.

Temperature control heat sink - In another proposed system, the sphere would be cooled by a contained volume of gel which freezes at -10°F and has a specific heat equal to that of water. The gel would be located under the floor in the bilge in a well insulated container with refrigeration coils running through it. Before a dive, a support ship refrigeration unit would be connected to the refrigeration coils and the gel would be cooled to -30°F. The coils would then be purged of freon, connected to the cabin heat exchanger, and the whole system filled with water-glycol solution. A variable speed pump would circulate the coolant through the "ice block" coils and the cabin heat exchanger during a dive. This very simple system could cool the cabin even in warm water and would require a minimum of on-board power to operate. The cost and development of this system would be low. The main disadvantage to the system is the space required for the four to five cubic feet of gel required for a 12 hour mission. This system would also add approximately four hundred pounds of weight to the vehicle. This weight, however, could be offset by the savings in batteries needed to power the system and the space could be located in any unused, unaccessible area such as the bilge.

Air type hull scrubber - In another simple system proposed, cooling would be accomplished by pumping air through spiral ducting behind the insulation on the lower half of the sphere. Temperature would be regulated by control of the air flow scrubbing the hull and condensate would form on the hull and be collected in the bilge. This system, although it would cool well in cold water, has several inherent disadvantages. A fairly large blower (1/4 HP) and flow rates up to 100 CFM would be required, creating a high noise level, and too high a circulation rate for human comfort. This problem would become very acute in warmer waters where the cooling efficiency would be very low.

22. SPHERE LAYOUT AND HUMAN FACTORS

Since the performance of the crew in the sphere would be a direct function of their comfort and efficiency, the sphere layout and human factors would be quite important. The environment would be a seven foot diameter sphere containing a pilot and one or two scientific observers for a 12 hour mission. This would include a possible one-hour predive checkout, three-hour descent, five-hour bottom time and three-hour ascent. Five seating and console arrangements were studied and the basic features of each listed. In the arrangement selected there would be seating for all three occupants and an inflatable couch on which to lay if observing directly through the viewports, (see Figure). Also located within the sphere would be scientific instrumentation of various types, the vehicle maneuvering controls, systems monitoring units and the necessary life support equipment.

The seats should be sturdy and rigid for various ascent, descent, and trim angles; yet have some fore and aft adjustment relative to the console. They should be comfortable for long periods of time, have head and arm rests, and have the ability to partially fold up and stow against or under the console. Steps could be provided on the back of one of the seats to serve as a ladder to and from the hatch. In the center of the floor there could be a small well in which a person could stand to stretch after being seated for several hours. The control console would be located directly in front of each person and maneuvering controls would fold down into a flat portion of the console which could retract to make it easier for a person to get in and out of the chair.

The sphere lighting system would be a variable level system providing a relatively high level while using instruments and a low level when making visual observations through the viewports. The use of electroluminescense systems for the low level lighting should be considered because of their low brightness and power consumption.

23. INSTRUMENTATION

Beyond the study of overall arrangement of the vehicle and sphere internal arrangement layouts no detailed study of instrumentation placement was done. However, with the basic vehicle layout, scientific well placement and provisions for a variety of bow mounted experiments, considerable flexibility would be available. Flexibility would be important for such a vehicle in order to perform a large variety of missions and experiments effectively.

24. CONCLUSIONS

The work done was for the purpose of defining possible alternatives and recommending directions for the development of preliminary designs. Costs, particularly for the support ship, will obviously be of paramount importance in making final decisions. However, a variety of alternate systems having excellent mission capabilities is possible today.

ACKNOWLEDGEMENTS

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ARL CONVERSION

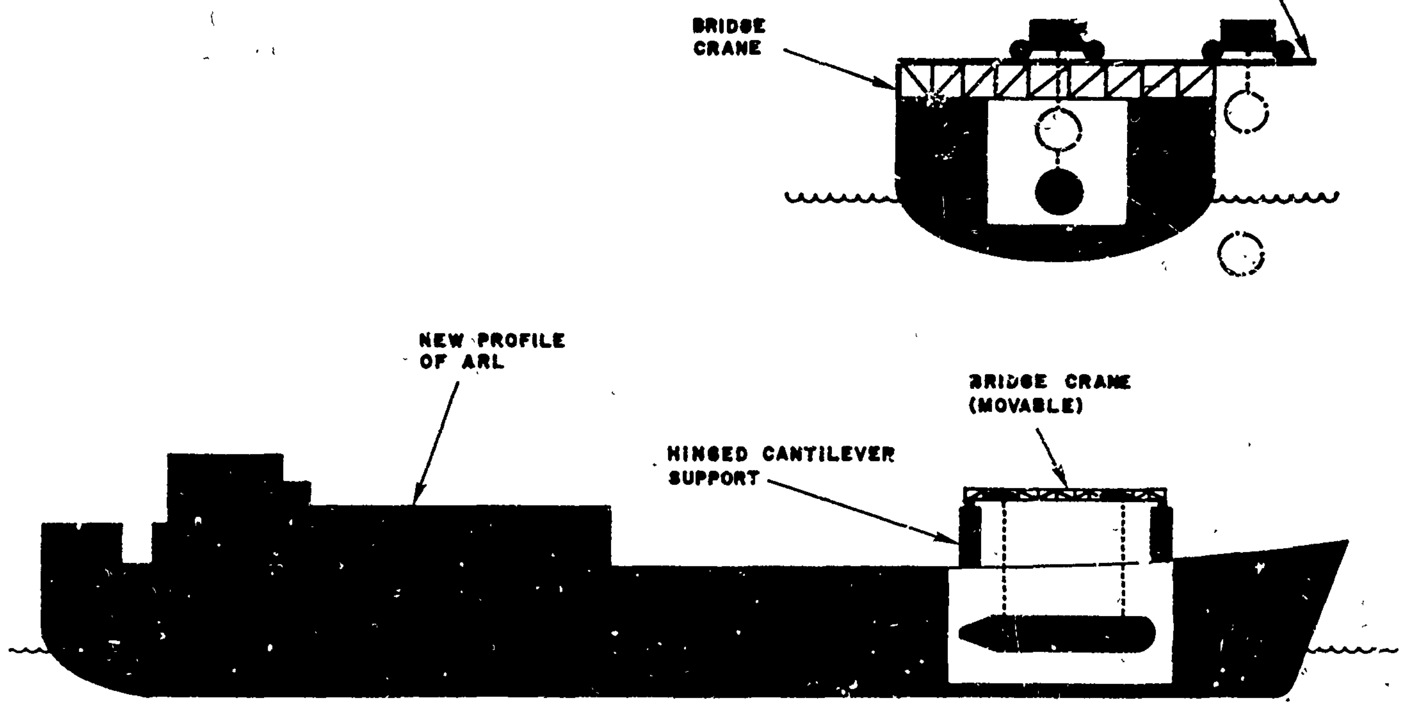


Fig 1

ARS(D) CONVERSION

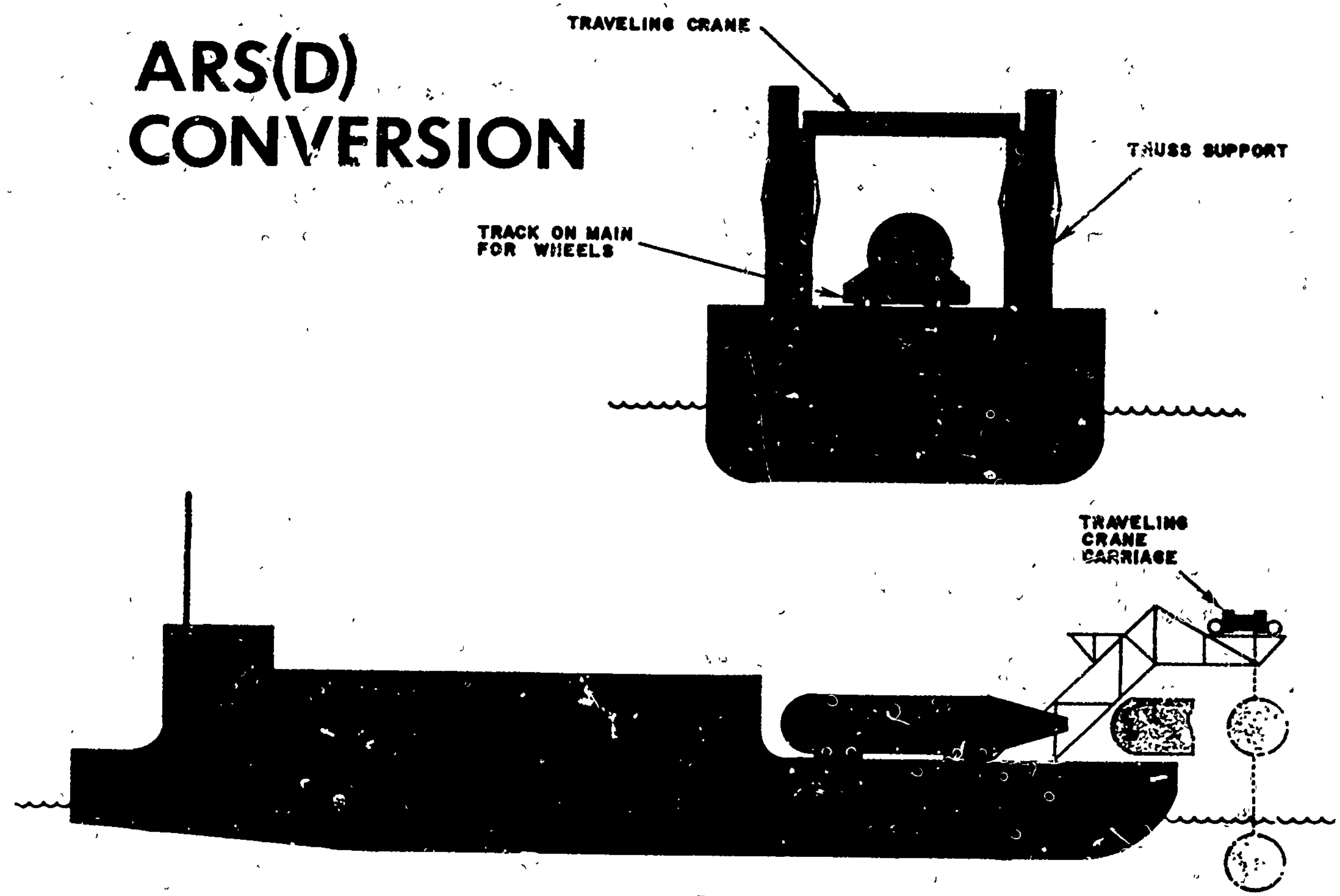


Fig. 2

AVP CONVERSION

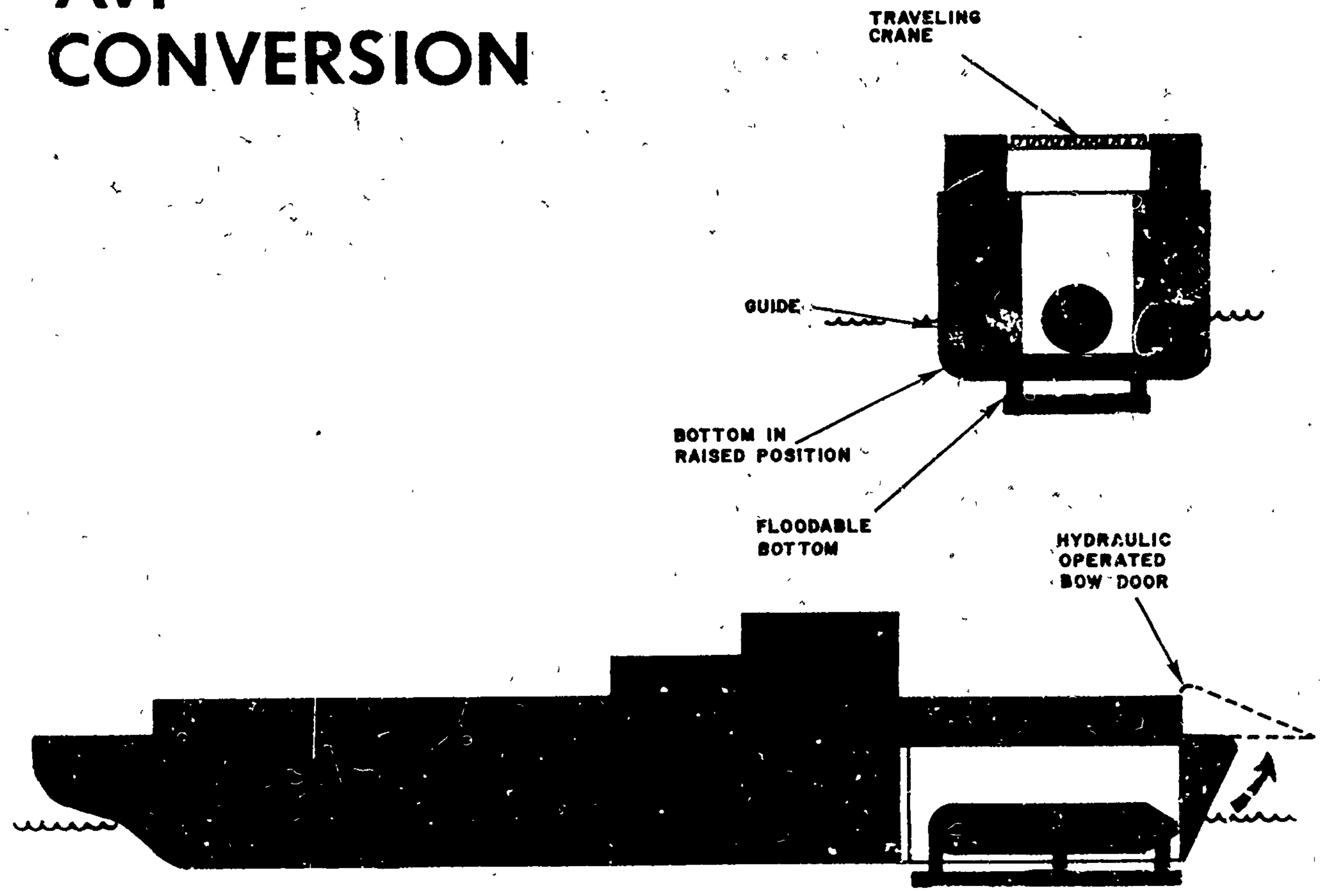


Fig. 3

Non-Self Propelled Support Ship

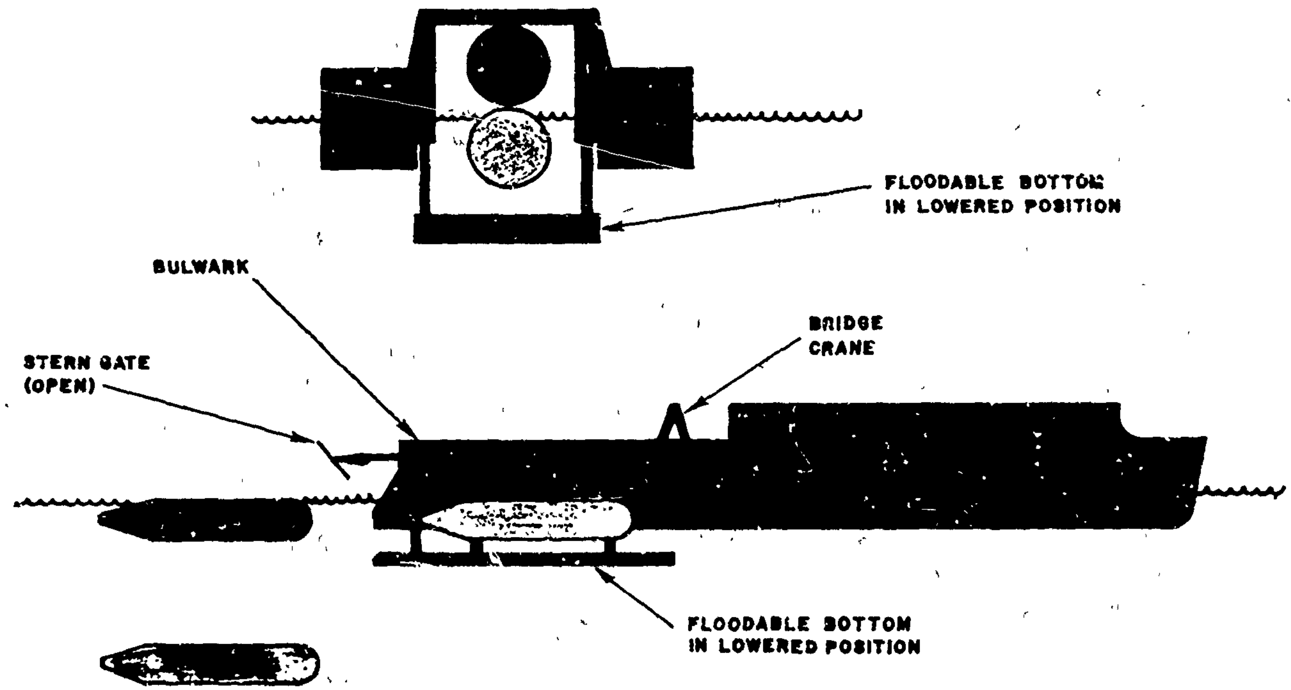


Fig. 4

Catamaran

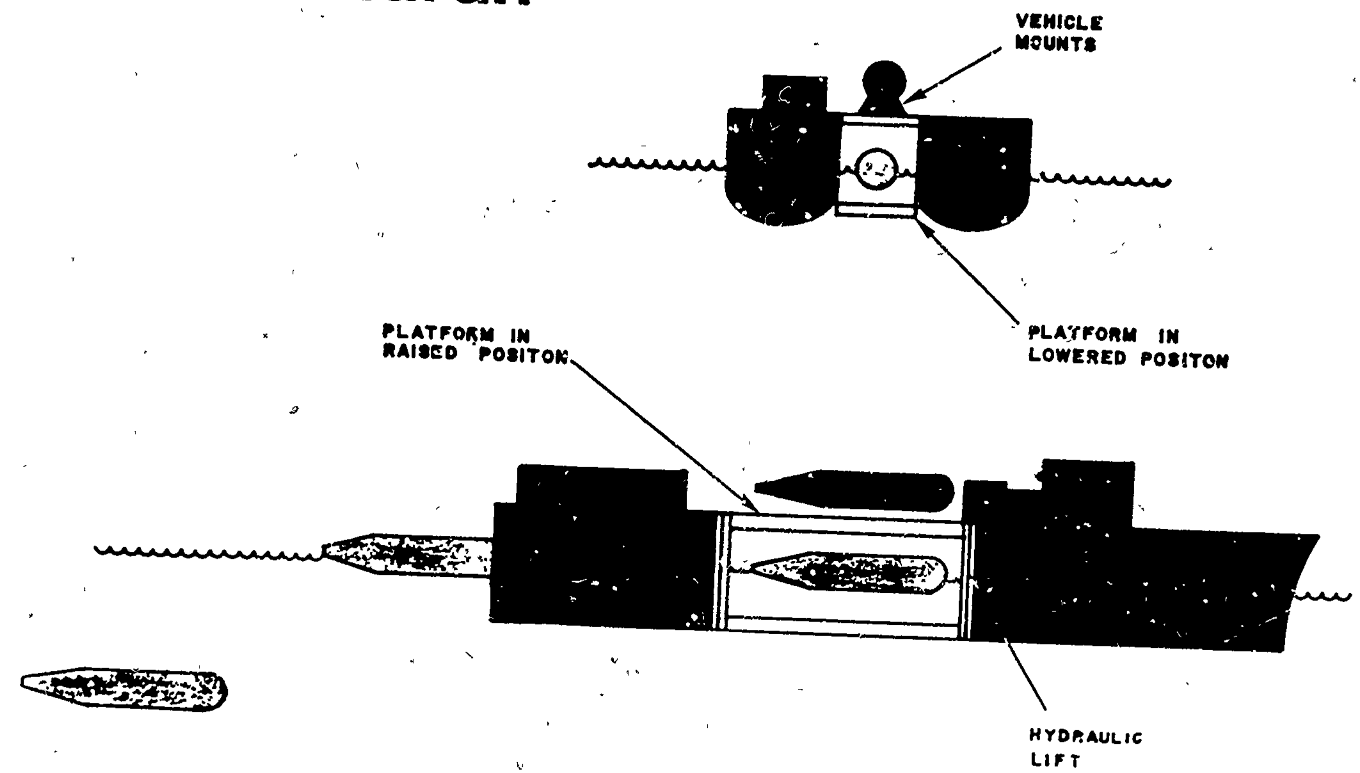


Fig. 5

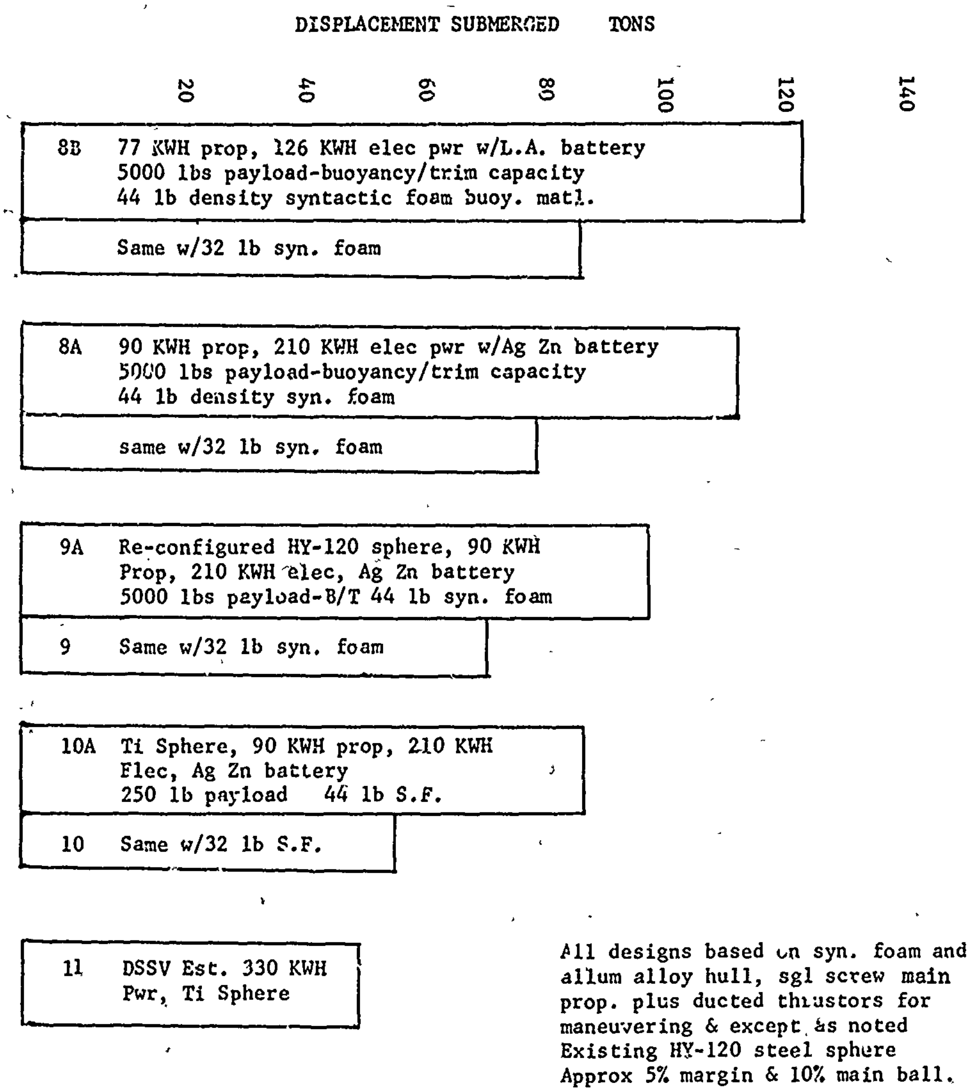


Fig. 6 - Relative Size Estimates

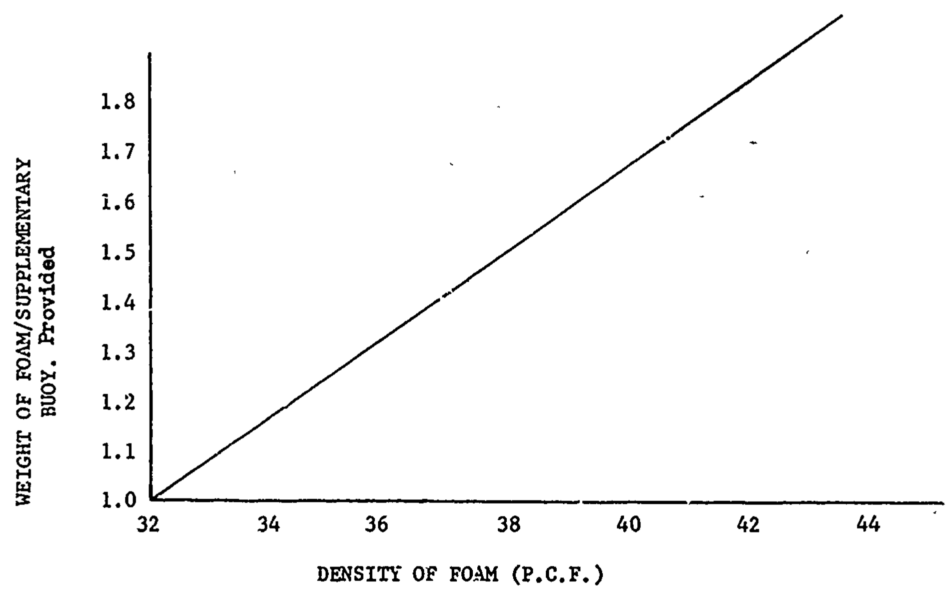


Fig. 7

Weight of Foam Required for Supplementary Buoyancy Provided Versus Density

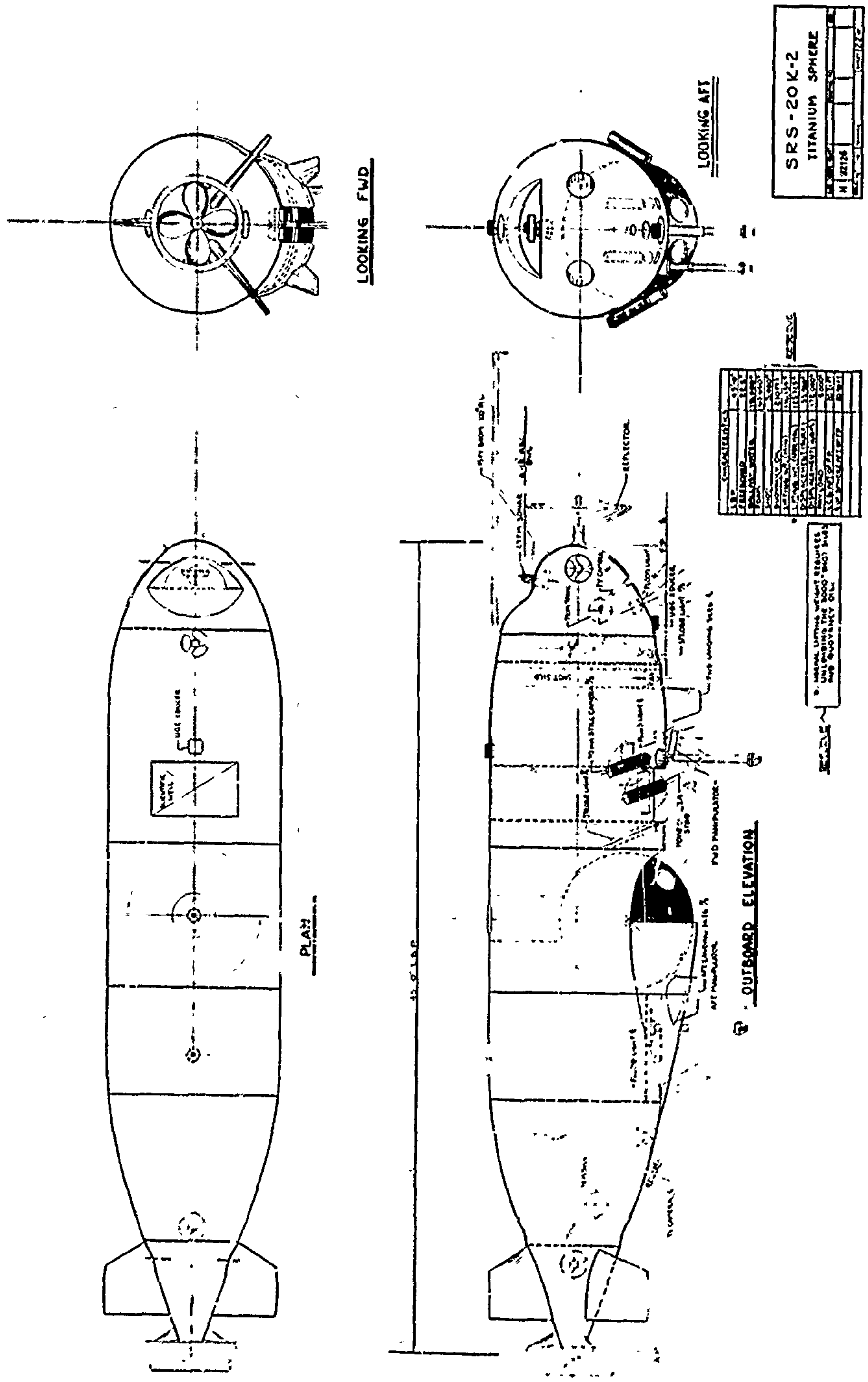
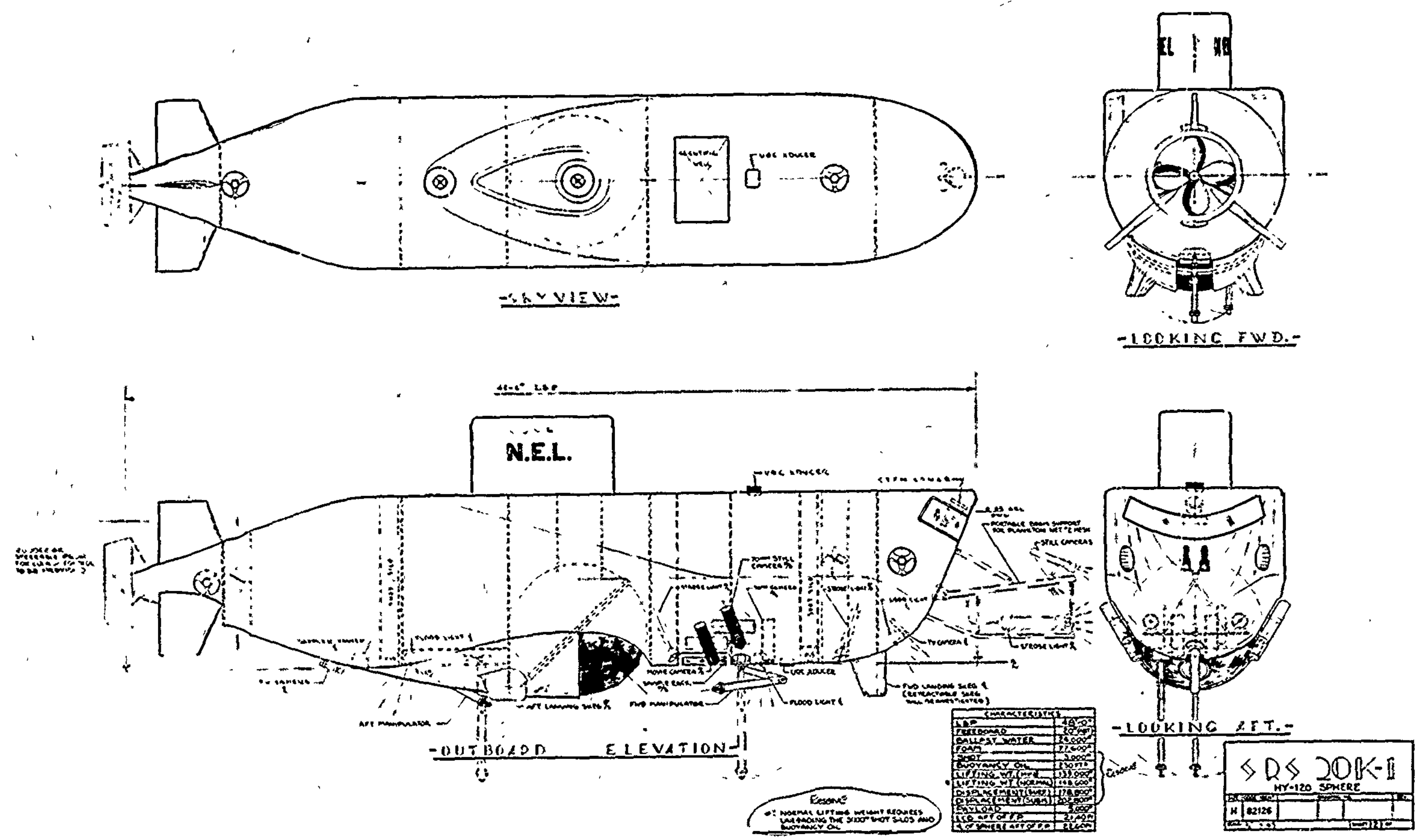

LOOKING FWD
LOOKING AFT
SRS-20K-2
TITANIUM SPHERE
PLAN
OUTBOARD ELEVATION
REFLECTOR
FWD MANIPULATOR
AFT MANIPULATOR

Fig. 8



SKY VIEW
LOOKING FWD.
N.E.L.
OUTBOARD ELEVATION
LOOKING AFT.
SDS 20K-II
HY-120 SPHERE

Fig. 9

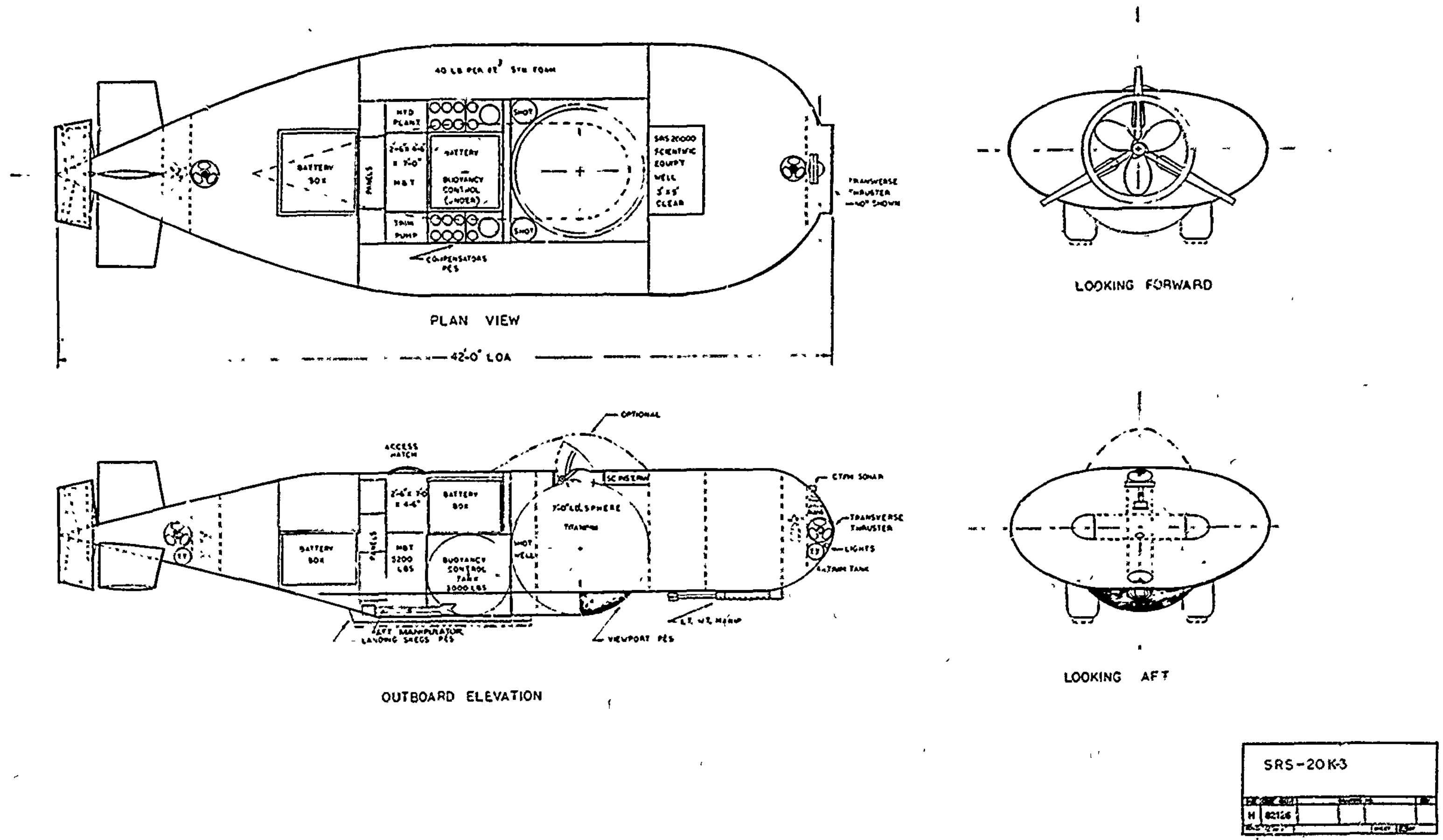

PLAN VIEW
42'-0" LOA
LOOKING FORWARD
OUTBOARD ELEVATION
LOOKING AFT
SRS-20K-3

Fig. 10

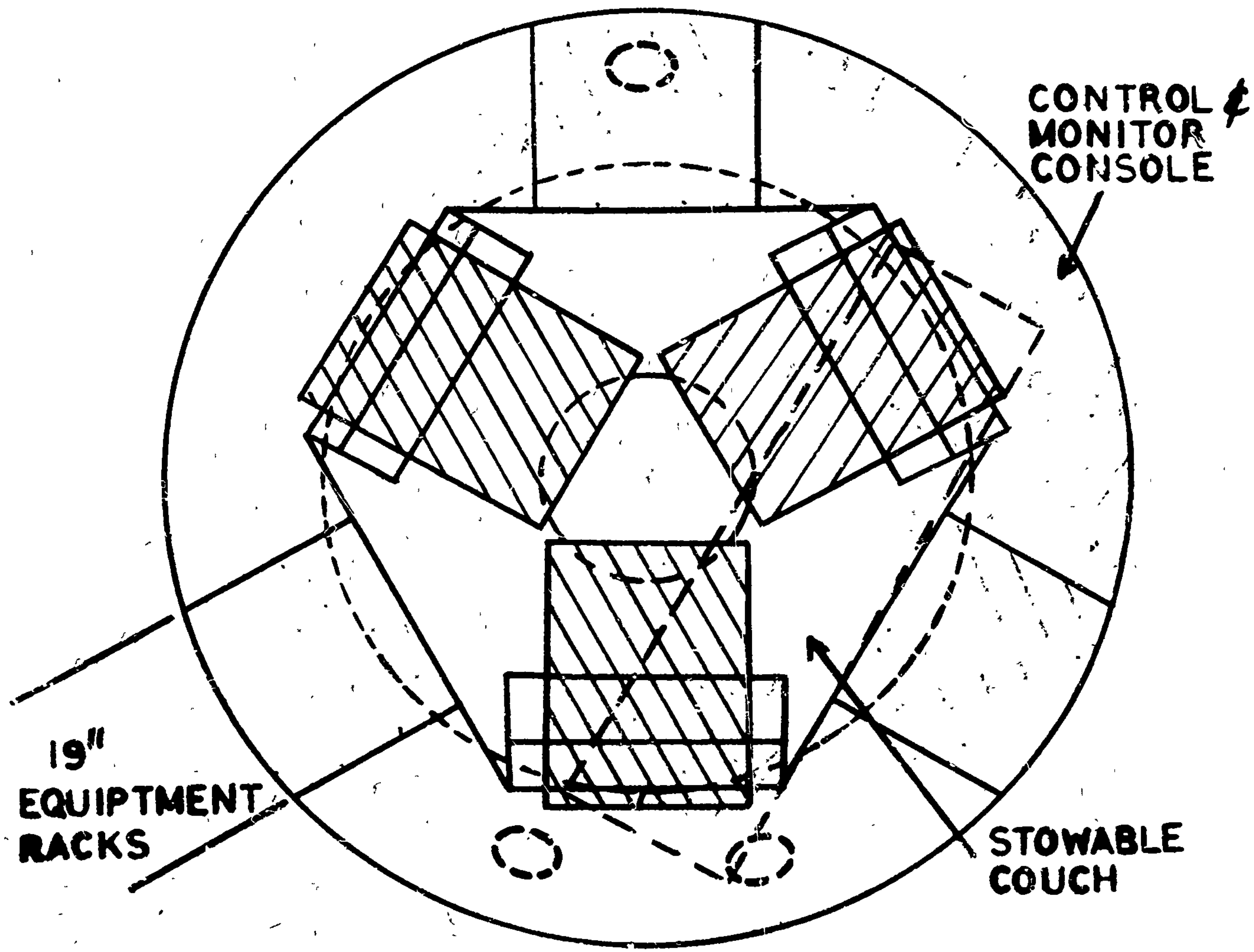


Fig. 11 - Sphere Layout

BENEFITS TO MILITARY OCEANOGRAPHY FROM MANNED SUBMERSIBLES

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ABSTRACT

The short operating history of the manned submersible has produced a wide variety of benefits to military oceanography in the form of scientific awareness and engineering progress. The limitations of conventional, over-the-side environmental sampling techniques have been more clearly defined through use of submersibles and indicate serious deficiencies in detailed investigations. Application of submersibles has clearly demonstrated the benefits of man's personally extending the capabilities of surface ships and towed devices to finalize search, salvage or identification missions. Introduction and employment of new materials, components and operational techniques have laid the foundation for improved Naval submersibles such as NR-1, the DSRV, the DSSV and TURTLE, and improvements in virtually any undersea hardware or instruments. The greatest benefit, however, has been in firmly establishing the fact that an unparalleled system exists by which the details of the ocean environment can be assessed to provide comprehensive understanding, and thus full utilization, of the ocean, be it military, politic or economic.

INTRODUCTION

In the 5 1/2 years since the Navy Undersea Research and Development Center (then NEL) contracted for the Navy's first lease of an industry-owned submersible, manned submersibles have played a small but significant role in developing our knowledge of the sea. It is the intent of this paper to present the significant benefits derived by military oceanography through use of these unique platforms.

This evaluation deals with those benefits derived from programs which had as their objective the measurement or understanding of the ocean environment, and includes benefits derived in terms of instrument effectiveness and establishment of new operational techniques which resulted during the course of these and other missions. Similarly, increased knowledge in other areas such as vehicle design, launch/retrieval systems, and materials performance are benefits which are also considered.

DEVELOPMENT AND UTILIZATION

DEVELOPMENT

Development of interest in the manned submersible as an oceanographic tool obtained its greatest impetus from the accomplishments of TRIESTE. While its dive to the bottom of the Challenger Deep was an outstanding technical achievement, TRIESTE's direct value to the environmentalist began to emerge in the subsequent dives conducted by NURDC. Concurrently, the constraints and deficiencies of a bathyscaph-type platform were being identified, and provided guidelines to the design of present submersibles.

In 1965 the list of American-built submersibles began to grow significantly, and interest in military use of this capability grew accordingly. Initially, the most effective and primary instrument employed was the human eyeball. Oceanographic instruments attached to the submersible were very unsophisticated, and those which were complex generally failed to work. Manufacturers' brochures were found to be overly enthusiastic in terms of vehicle capability, and breakdowns of the larger, deep-diving submersibles were common. But this was to be expected, for it was unrealistic to think that submersibles just launched would commence flawless performance. Consequently, a great deal of learning had to be gained, and the owner had to shake down his vehicle to get rid of all the "bugs". The scientist, on the other hand, had to learn, through trial and error, what instruments could be employed effectively and which projects were realistic or beyond the submersible's capability.

But this early learning was quite profitable. We learned, for example, how utterly dependent we are on electrical connectors and penetrators; how difficult it is to "fly" a controlled path; how sea-state dependent are launch and retrieval; how varied are the definitions of "payload"; how uncomfortable it can be to look out a viewport for long periods, and, not the least important, how to write a contract which was neither hopelessly inadequate or unrealistically over-ambitious. In short, adolescence had arrived, but was often accompanied with severe growing pains.

By 1967 various Naval activities began to realize many of the constraints placed on a submersible, and were finding out what to look for in a submersible to perform their particular tasks. Owners of vehicles also began to realize their own shortcomings, and modifications to both the vehicle and the operational procedures became evident. Instruments designed specifically for submersibles were being developed which could be adapted to different vehicles and work in the hostile internal as well as external environment. Operational experience began accumulating to the point where more specific and realistic planning could be conducted, and the support crews of the vehicles began to work as skilled, experienced teams. Similarly, the Naval users themselves began to specialize into particular aspects of studies from submersibles, and individuals began emerging who could be consulted on the practicability of conducting specific types of work from submersibles.

The past year or two has begun to reflect the effort and funds placed into the development of this expertise on the part of both the Naval user and the owners. Reports of significant value have been published which delineate the scientific accomplishments of the submersibles, and the salvage/search accomplishments dramatically demonstrated the usefulness and role of this unique tool. But this by no means infers that we have reached the apex of the learning curve. There are still numerous design and material problems, instrument problems, and operational problems to be overcome before any operation by any Naval activity will be conducted routinely "as planned". And it is indeed unfortunate that the attainment of the routine submersible operation will be delayed owing to the present lack of submersible leasing funds which has affected the entire Naval scientific community.

UTILIZATION

The information presented in Tables I and II (obtained from a report by LCDR Duane Beving, CNM), represents the Naval activities who participated in submersible operations, the dives they made, and the purpose of the dives.

One arbitrary figure in these tables is the number of dives made by BEN FRANKLIN during its cooperative program with NAVOCEANO. Whereas most submersible dives are from 4 to 8 hrs. duration, I have taken an average of 6 hours/dive and divided it into 730 hours (30.5-day duration of Gulf Stream Drift Mission) to obtain 122 dives. This manipulation should serve to alert the "bean counters" who follow the dubious practice of dividing total dives into total dollars to get an average cost for each dive, and then proceed to compare cost per dive on a long duration vehicle (BEN FRANKLIN, ALUMINAUT) against that of the short duration vehicles (DEEPSTAR-4000, STAR III, etc..). Although beyond the scope of this report, the suggestion is made to compare cost/hrs. submerged if one finds the need to arrive at an average value. If this practice is not followed one is left with the dilemma of comparing equally the one 30-day BEN FRANKLIN dive with one 5-hour DEEPSTAR-4000 dive.

DIVING PROGRAMS AND RESULTS

The following section highlights the reported programs and the significant results of these programs as pursued by Naval activities. In some instances operations are described which, although not pursued by the Navy, have demonstrated capabilities directly applicable and available to military requirements. Although I have attempted to include the results of all operations, there are some which are still in the report preparation stage and not yet available.

Specific reported examples of the submersible's unique capability to procure data unattainable through other methods is described on the following pages. But the large majority of submersible dives have been to augment or confirm previous surface studies; as a result, the impact of these dives may be incorporated into larger reports not dealing specifically with the submersible's contribution. In other instances, the dive may have been for selection of a hardware site and no report was required. ALVIN's operations in the Azores for USNUSL is one example of this latter type operation where only two of three previously selected hardware sites were found suitable. Additionally, instances where special equipment was fabricated to collect data or to be tested on the submersible and then failed in the operating environment constitute another significant proportion of dives.

Such operations constitute the great majority of submersible dives. The results, while not reported, are equally as important as the dives where new discoveries are made, because they have provided the oceanographer and the engineer an awareness of the environment unobtainable from surface ships. That the ocean bottom is not flat is nothing new, but to personally observe how "unflat" it actually can be is a dramatic experience. Almost our entire concept of the ocean bottom topography is obtained from acoustic soundings and, in small part, from bottom photographs. To personally observe boulders as large as automobiles and vertical cliffs several hundred feet high forces one to look with a new view at interpretation of wide-angle acoustic soundings. To find oneself unable to maneuver in 0.5-to 1.0-knot currents instills a greater respect for "slow" currents when designing bottom-mounted hardware. Being able to visually discern ambient sunlight at depths of 2100 feet puts new meaning into light measurements (Fig. 1). And to observe the many and varied changes in sediment type and distribution in a small local area forces the scientist to reassess the effectiveness of surface-obtained samples and subsequent wide-scale extrapolations based on such data.

Such observations and experience have provided the military oceanographer considerable food for thought in later surface-oriented operations when interpretation of statistically-sampled data was involved. Likewise, the engineer and equipment designers, after seeing how crooked and snarled their undersea cables actually are, approach new designs and installations with greater appreciation of the problems involved. In this aspect the experience of DOWB in finding that many of the hydrophones planted in a Pacific tracking range ended up on their sides after installation from the surface (Momsen, personal communication) forces one to question the disposition of all "upright" bottom-mounted structures (Fig. 2).

It is the results of such indoctrination which have provided the bulk of the benefits to military oceanography in terms of a new and more cautious approach to data interpretation, instrument effectiveness, and operational techniques of equipment installation. While such results are not generally published, they can be seen in the planning and conduct of present and future scientific and engineering projects.

TOPOGRAPHY

Measurements of water depth (bathymetry) have been conducted for many years with sounding lines and sonar (echo soundings); the results are generally more than adequate for surface ship navigation. Measurements of bottom relief relative to a reference point (topography) can also be conducted with the same devices but the results must be treated with caution. The shortcomings of the lead line in deep water are obvious; the shortcomings of sonic methods, though not so obvious, are almost as great when the results are used to reconstruct topography. The problem is that of beam spreading with depth, which results in receiving a return from the closest reflecting object rather than that object directly beneath the sounding ship. Under such circumstance vertical cliffs, overhanging outcrops and many other irregularities are masked to the extent that they are completely missed by both the wide (60°) and narrow (3°) sonic beam.

As an example, while investigating the La Jolla Fan Valley from the bathyscaph TRIESTE I, Moore (1963) reported that observations below 3000 feet depth revealed topographic features of quite different scale than those recorded by echo sounders. While the echo sounder showed the general configuration and meanders of the Fan Valley, it did not show the steep-walled and narrow erosional nature of the deepest channel within the valley. Additionally, flattopped, narrow, but quite distinct terraces flanking the valley were not revealed through echo soundings. At a later date, Shepard et al (1964) investigated the La Jolla and Scripps Submarine Canyons from the much smaller submersible DIVING SAUCER. In places the canyon walls were so narrow that the three-meter diameter submersible could not enter and, observing the large number of overhanging walls, the authors stated, "Since there are many overhanging walls, it is clear that even the detailed soundings made previously by echo and wire sounding techniques were misleading for some places".

In an unpublished manuscript presented at a workshop on Deep Research Vehicles at Woods Hole Oceanographic Institution in November 1967, Dr. Shepard, of Scripps Institute of Oceanography, pointed out other incidents where the submersible provided entirely new data on submarine topography:

a) Extensive wire soundings provided a good idea of the Scripps and La Jolla Canyons' average profile and gradient, but completely missed the fact that the floor descended in steps of almost vertical drops alternating with gentler, almost horizontal sections.

b) Owing to side echoes, which masked its presence, a vertical cliff was unexpectedly discovered at the edge of the continental shelf off La Jolla.

c) Rock benches too small to appear on fathograms were discovered at 480 feet off San Diego where extensive surface observation has given no indication of their existence.

Subsequent investigation of the submerged rock benches off San Diego was conducted by R.F. Dill (1967) in DEEPSTAR-4000. Not one, but a series of these terraces (between depths of 325 to 1170 feet) were observed which were less than 100 feet wide and 60 feet high. Most significantly, few of these submerged terraces show on profiles across the continental slope made with conventional echo sounding equipment.

Further evidence of rough topography not revealed through conventional techniques was presented by Busby and Merrifield (1967) who reported the extensive occurrence of near-vertical outcrops and extremely large boulders from observations with ALVIN in the Tongue of the Ocean, Bahamas. These irregularities, although not completely unexpected, were indicated in only one instance during extensive surveys of this area by a variety of investigators. In this same geographic area, Markel (1968) reported that a search from ALUMINAUT for the recently-sunken cruise ship YARMOUTH CASTLE was thwarted owing to deep, wide, hogback ridges and troughs into which the football-field-sized liner settled and precluded visual or sonic detection. According to Markel, the most up-to-date available bathymetric information indicated a relatively flat bottom of approximately 10 percent bottom slope.

One of the more dramatic comparisons of topography as determined from conventional surface-oriented means and the submersible is presented by Busby (1969) from studies conducted off Vieques Island, Puerto Rico. On repetitive cruises from 6000 feet to 100 feet depth the bottom was observed, photographed, and sketched. This area had previously been surveyed by another group using conventional echo sounding (60° beam angle) equipment. When compared, the picture of the bottom produced by these two separate techniques (Fig. 3) yields a picture that is striking, and indicates that the echo sounding techniques employed can be used only to show general slope gradients and depth. The submersible, on the other hand, revealed exact details of the topography. A similar conclusion was reached by Emery and Ross (1968) during studies with ALVIN off the northeast coast of the United States; they concluded that "The use of research submarines provided a means for discovery and study of sea floor features too small for investigation by soundings from surface ships and too large for chance underwater photographs".

GEOLOGY AND GEOLOGIC PROCESSES

Coincident with bottom topography have been studies determining the dynamic processes acting to modify the bottom and investigations into the composition of surficial unconsolidated sediment and outcropping or buried bedrock. One of the first to demonstrate the advantages of direct viewing was Moore's (1963) observations from TRIESTE off San Diego. One of the primary purposes of this study was to compare visual observations with geophysical results which showed the basin slopes to be structurally controlled with a thin, if any, cover of sediment. Samples taken previously indicated the sea floor to be covered with fine to silty sand. Conversely, acoustic probes suggested that truncated, seaward-dipping bedrock should be exposed or very shallowly buried. The dilemma was resolved when the giant white sea anemone (Metridium sp.), which requires a firm sub-stratum for attachment, was observed growing on the fine sand bottom. This organism indicated that solid bedrock, as suggested by the sonic probes, was present, but covered by a thin veneer of sediment. Moore (ibid) points out that instances such as these emphasize the inadequacy of surface grab sampling when a thin covering of sand can exert such influence on the interpretation of results.

Dr. Shepard's presentation at the WHOI DRV workshop (op. cit.) also included examples where the submersible uniquely contributed to geological studies. In one study, although numerous past investigations with lowered cameras had been made, it was not until a submersible was used that recently eroded, polished and grooved zones were discovered near the base of vertical walls in Scripps Canyon. Off Cape San Lucas, Baja California, submersible dives produced a picture of the environment virtually unexpected, although, as Dr. Shepard points out, extensive operations with surface ships had failed to show the actual conditions.

A recent study of submerged mounds on the outer edge of the Blake Plateau from ALVIN showed them to be a series of linear ridges and troughs capped by living coral (Milliman et al, 1967) rather than actual coral reefs as suspected from previous surface-obtained data by Stetson et al (in Milliman et al, 1967).

The capability of being able to select the object one wishes to sample is so fundamental to the conduct of good science and engineering that to mention it seemingly belabors the obvious. However, this selectivity is one advantage that cannot be matched at present by any method other than the submersible; the theories of ocean bottom composition and dynamics will be suspect as long as they are based on data obtained from a sampler dangling at the end of several miles of cable.

BIOLOGICAL STUDIES

In the past, net hauls taken from the surface through acoustic scattering layers more frequently returned virtually empty or dominated by insufficient numbers or types of animals to account for the reflection of sound observed. The preponderance of evidence indicated the mesopelagic fishes; specifically, lantern fish of the family Myctophidae (Hersey and Backus, 1962). During a series of dives in TRIESTE off San Diego, Barham (1963) discovered another candidate of equal importance: a jellyfish-like organism, the physonect siphonophore. Fulfilling all the prerequisites of a sound scattering organism, as well as occurring worldwide, the siphonophore has been shown to be an integral component of the DSL. Barham pointed out that the fragile nature of the jellyfish accounted for his not being considered heretofore, because on contact with the sampling net the colony is destroyed and most are lost through the large net mesh. Further, owing to their pellucid nature they are extremely hard to photograph or televise, and, although they had been observed on other bathyscaph dives at DSL depths, the investigations did not relate them to scattering zones (Barham 1963). Barham (1969) later captured a new species of jellyfish from DEEPSTAR-4000 which was appropriately named Deepstaria enigmatica. In another case he photographed and described a unidentifiable species of flatfish from DIVING SAUCER (Barham, 1966).

In other ocean areas direct identification of components of the DSL from submersibles such as ALVIN and DEEPSTAR-4000 has removed some of the mystery surrounding the composition of this phenomenon (Backus et al, 1968; and Milliman and Manheim 1968).

In studies of macrobenthos of the San Diego Trough, Barham and his associates noted the case in which the holothurian Scotoplanes sp. was swept off its feet by the motion of the slowly-moving bathyscaph TRIESTE. Combining this observation with the results of a previous surface-oriented grab sampling program of the same area in which Scotoplanes was absent, the authors surmised that the rapidly-descending grab sampler used could produce a preceeding shock wave that washed the holothurians aside. Experiments by Wigley (in Barham et al, 1967) showed that this is quite possible with some types of grab samplers. Barham (ibid) also noted that, instead of being repelled by the bathyscaph, benthic animals appear unaffected and in some instances are actually attracted by the vehicle. This has also been the author's experience in dives with ten different vehicles; the only possibly negative response has been in the DSL off New London, Conn. when the myctophids composing the layer swam upside down, possibly to avoid the vehicle's lights. It is likely that the noise of the submersible's motors might also repel some organisms.

The submersible ALUMINAUT was used by the commercial fishing industry to confirm what had only been suspected from the results of surface observation. Unusually high and unusually low catches of the calico scallop (Pecten gibbus) had been reported from dredge hauls through an area off New Smyrna Beach, Florida. Diving in ALUMINAUT, biologists observed the scallops to occur in 100 to 300-foot-wide zones separated by barren sandy areas. Consequently, when the dredge passed at right angles through the zones the catch was low; when it passed within and parallel to the zone the catch was high (Taylor, 1967).

The advantages of the submersible to the marine biologist are manifold and, as these examples have shown, indirect methods of sampling are not always reliable. As noted by Barham (1967), the observer can study the large organisms in their natural environment and note interrelationships and behavioral characteristics which are impossible to obtain from sampling techniques and difficult to interpret from photographs.

PHYSICAL MEASUREMENTS

Dr. Shepard remarked that it is probably a matter of debate whether the submersible is the best or most economical method of measuring currents. But he raised the point of strategically locating bottom-mounted current meters, and in this aspect the submersible is invaluable, especially in the topographically-rough areas of the continental shelf and slope. Busby and Merrifield (1967) showed vertical cliffs 60 feet high at 700 fathoms depth in the Bahamas where the silty calcareous sediment was ripple-marked at the base and featureless at the plateau. A current of 0.4 knots was measured from ALVIN on the ripple-marked area and less than 0.05 knots was measured on the plateau (Fig. 4). Shepard (1965) reported currents in excess of the 0.5-knot propulsive power of DIVING SAUCER flowing down submarine canyon areas and then reversing their flow upslope during the same dive. This same phenomenon has been reported in the Ladonia Submarine Canyon off Cape Cod from ALVIN (McCamis, personal communication). Rechnitzer (1962) pointed to the discovery of intermittent deep bottom currents which were unknown prior to the bathyscaph dives.

The above observations indicate that variations in current speed and direction within a short time can and do occur regularly, especially on the continental slope. The importance of such observations is of decided interest to the investigator who wishes to obtain a representative picture of current flow and must plant his current meter in one of these highly variable areas. It is in determining the representativeness of near-bottom data that the submersible demonstrates an advantage over the procedure of blindly planting instruments from the surface.

Since the early days of the bathyscaph dives one of the more intriguing phenomena that has been observed is the presence of particles in the water column which, in the vehicle's lights, are similar to dust particles seen in a ray of sun. These particles have been present on all dives made by the author and have been reported by others (Lafond, 1962; Rechnitzer, 1962; Milliman et al, 1967). Rechnitzer (ibid) stated that this "snow" was always present, to a greater or lesser degree, on all dives by TRIESTE; he also remarked that, to the contrary, FNRS-3 reported the presence of a crystallineclear layer near the sea floor. Milliman et al (op. cit.) conducted a series of dives in ALVIN on the Blake Plateau off Charleston, South Carolina in which they sampled and analyzed the "snow" in that area. The results of the analyses revealed that the "snow" is predominantly organic detritus suspended in the water column. The significance of this observation is that underwater photographs never showed these particles, and in many instances the water has been referred to a "distilled" based on photographic evidence. Although the scientific significance of this phenomenon is unknown, it is sufficient to note that a major property of sea water has been unappreciated since the conception of oceanography.

ACOUSTICS

In 1956 Hamilton and others measured sediment sound velocities in situ with diver-held devices. Discussing these measurements in a subsequent report, Hamilton (1963) pointed out that the errors inherent in the diver-obtained measurements were larger than the change of sound speed owing to temperature, pressure or other small factors, but by taking similar measurements in situ with TRIESTE in deep water the changes became significant. Three bottom stations were occupied by TRIESTE, and in situ sea-floor sound velocity measurements were made in depths between 338 and 1235 meters off San Diego. In brief, results of this work were to confirm previous predictions of sound speed for fine-grained, high porosity sediments, but predictions based on the same sound-speed vs. porosity curves need revision for sands where studies are indicated.

Working from ALUMINAUT in two areas off the southern shore of Vieques Island, Puerto Rico, Haigh (unpublished manuscript) observed: 1) variation in acoustic bottom loss which may be attributed to more intensive micro-topographic relief in one area than in the other, and 2) an extremely low value of measured reflectivity virtually independent of frequency. To decrease instrumentation errors, ALUMINAUT was equipped with a broad-band, calibrated hydrophone which received the direct pulse from a surface-generated charge (standard No. 8 Dupont blasting cap), the bottom-reflected pulse from 100 feet below ALUMINAUT, and, as an unexpected bonus, the surface-reflected ping. The results of 98 shots (50 at one site; 48 at the other) show, after exhaustive analyses, bottom losses of 1.15 db compared to the lowest value of 6 db normally obtained from surface measurements. No satisfactory explanation can be provided at this time but the evidence strongly encourages further investigations to resolve the enigma. Haigh further emphasizes the low standard deviation of the results (2.29 vs. 4 from surface observations) to point out the advantages of using a stable submersible for acoustic work of this type.

Using DIVING SAUCER off San Diego in 1965, Assard and Hassell (1966) verified the spatial correlation of ambient noise in the horizontal and vertical planes at two different depths. In their objective of determining the extent of agreement between theoretical values and the experimental values obtained aboard DIVING SAUCER, the authors found that the submersible offered the unique advantage of placing the observer in the environment, thereby enabling him to concurrently monitor the data and position the equipment while hovering at constant depth in an extremely "dead ship".

Although none of the acoustic studies reported to date have been completely free of various instrument or operational problems, the application of the submersible to these and other studies (Mackenzie, 1961; Buffington et al, 1967) is indicative of its advantage to the acoustician. The submersible offers the unique capability of carrying instruments to the bottom or into the water column and positioning or applying these instruments as the investigator desires, not as the currents or a spinning wire desire. With this capability the acoustician has successfully applied the submersible to verify theoretical predictions by in situ measurements.

GEOPHYSICS

Economical regional geophysical mapping (gravity and magnetics) is beyond the capability of present submersibles. As a method of verifying surface-obtained data, however, the submersible is excellent. Thompson (1968) has summarized the geophysical work conducted from submersibles and submarines and, based on field tests with ALUMINAUT, reports that gravity meter readings were obtained with precisions of ± 0.2 milligal while sitting lightly on the bottom, ± 1 milligal while hovering and ± 2.5 milligal while "flying" horizontally. Thompson's work, and the results of others (Mackenzie, 1961; Busby and Merrifield, 1967) show that while measurements of greater precision can be taken from a submersible than from the surface, the accuracy of these readings is adversely affected by pitch oscillations of 80 to 90-second period in the vehicle (ALUMINAUT) caused by crew movement, inaccuracy in depth measurements in terms of feet, and grave deficiencies in navigation accuracy.

ENGINEERING

The advantage to placing the engineer in the environment to work, or observe, or direct others becomes abundantly clear when one attempts to inspect an item by lowering a television camera or photographic devices. First, the apparatus for inspection, dangling on the end of a line, is subject to vertical excursions in virtually a 1.5 ratio with the surface wave height; the results, to say the least, are marginal. When towing the lowered device additional problems are encountered in maintaining constant altitude which is required in cable or pipeline inspection. Finally, there is no present underwater television or photographic camera that can provide the depth perception, range, and color contrast to a degree comparable with the human eye. Such are the demonstrated advantages the submersible offers by virtue of its freedom of movement, control, and human occupant.

Inspections of cables and pipelines have been performed by many submersibles, and a few examples show their widespread application. Toggweiler (1963) described the inspection of a power cable from SUBMARAY across the 4.6 mile, 322-foot-deep Rosario Strait in Washington. SUBMARAY has been employed in other tasks such as inspecting sewer outfalls, pipelines and timber surveys. ASHERAH (Hull, 1967) is reported to have made a video tape recording of 20 miles of underwater cable for the Bonneville Power Authority. Electric Boat's STAR II and STAR III have been used to inspect oil wells and pipelines, and transatlantic cables for American Telephone and Telegraph Co. (Fead, 1968). ALUMINAUT conducted cable and hardware inspection in both the deep and shallow water of the Bahamas and the Virgin Islands and reported inspecting as much as 38 km of cable in 72 submerged hours (Markel, 1968). ALVIN conducted a series of dives off Bermuda to inspect cables and hardware in the vicinity of Plantagenet Bank (WHOI Ref. 66-22), and performed inspection and maintenance dives on hardware and cables in the Bahamas (Busby and Merrifield, 1967; WHOI Ref. 67-23).

Inspection of future sites for bottom hardware implantment is another area where the submersible has demonstrated its unique advantages. Pollio (1969) has shown how a bottom topographic contour chart of 2-in. contour interval and 0.5-in. accuracy can be compiled by photogrammetry from submersibles (Fig. 5). The subject of sediment bearing strength, of vital importance to design of bottom-mounted instruments, can be investigated _in situ_ from submersibles, and the tentative results of such measurements when compared against laboratory analyses indicate that significant discrepancies may be introduced by remotely-obtained shear strength measurements (Rucker _et al_, 1967; Buffington _et al_, 1967). Similarly, the local bottom slope can, if not accurately known, present difficulties to hardware or habitat performance. Buffington _et al_ (1967) described a method of measuring precise local bottom slope from DEEPSTAR-4000 that, if it had been applied, may well have avoided the installation and subsequent 11° tilt of the SEALAB II habitat caused by a comparable bottom slope.

SALVAGE, SEARCH, AND IDENTIFICATION

The first occasion to dramatically demonstrate the submersible's capability in search, salvage, and identification was in the search and positive identification of the lost nuclear submarine SSN THRESHER. Although the general area of suspected THRESHER debris had been found through surface-oriented techniques, it was not until TRIESTE made _in situ_ identification that the debris was positively identified as that of THRESHER. It is of more than passing interest to note that one group of searchers identified a portion of their own suspended camera as the remains of THRESHER. More recently, the remains of the nuclear submarine SSN SCORPION were impressively located and identified by towed devices from the research ship MIZAR in over 10,000 feet of water. The bathyscaph TRIESTE II was employed in the summer of 1969 to conduct detailed _in situ_ examination of the debris.

The manned submersible demonstrated beyond question the value of man-in-the-sea in the successful hunt for a lost hydrogen bomb off Palomares, Spain in 1966. In conjunction with a variety of towed and lowered acoustic and photo-optical devices the submersibles CUBMARINE, ALUMINAUT, and ALVIN conducted a search and identification mission lasting 80 days. Acoustic devices such as the Ocean Bottom Scanning Sonar (OBSS) and the Navy mine-hunter sonar (UQS-1) proved ineffective in the area where the bomb was finally located owing to the extreme roughness of the bottom which produced little besides reverberation in the sonar records. Although it could not determine the identity of a contact the UQS-1 could vector either divers or CUBMARINE to the target for positive identification (Andrews 1967). Finally, according to Andrews, in a combination of fortunate circumstances counterbalanced with the handicap of limited visibility ALVIN located the bomb at 2850 feet depth.

In a later salvage operation ALUMINAUT recovered a string of five (5) current meters lost during retrieval one year previous (Busby 1967) (Fig. 6). On the first dive ALUMINAUT visually inspected the entire length of line (3200 feet) to assure that its retrieval would not damage nearby arrays or their cables which constituted the St. Croix Tracking Range. On the following dive ALUMINAUT effected retrieval by attaching 2100 feet of nylon line at 3150 foot depth, ascending to the surface while the line paid out and then lifting the array the remaining 1000 feet to the surface. One of the more significant factors of this recovery was the determination by ALUMINAUT that recovery of the array would not be detrimental to other instruments in the recovery area. Obviously, dragging the area with grappling hooks would have been less expensive, but the possibility of hooking other devices were excellent.

In the U.S. Navy's underwater torpedo range at Dabob Bay in Puget Sound the manned submersible PISCES has been gainfully employed recovering torpedos from depths to 1300 feet. Cdr. J. Dodgen (personal communication) of the Keyport Naval Station reported that PISCES regularly retrieved up to as many as five torpedoes in eight hours, while an unmanned system (SORD), used for the same purpose, took as long as eight hours to retrieve one torpedo.

In early 1969 the submersible DEEP QUEST performed an invaluable chore for the aircraft industry. At a depth of 325 feet DEEP QUEST's manipulator picked up and carried to the surface the 18 x 9 x 5 inch flight recorder from an SAS airliner which crashed on 13 January 1969 on takeoff from Los Angeles. Six dives over a three week period were required to find and retrieve the recorder. Because of this demonstrated capability DEEP QUEST was chartered almost immediately to search for other recorders lost when a United Air Lines aircraft crashed in Santa Monica Bay on 18 January 1969. In five dives over an eleven day period DEEP QUEST again demonstrated her unique capability by retrieving the flight recorders from 950 feet of water (Ocean Science News, 7 March 1969).

The following July, the Canadian submersible PISCES performed an even more significant salvage feat at 670 feet depth in Howe Sound, British Columbia. Under a "payment if salvaged" contract with the Canadian Department of Transport, PISCES embarked to salvage the 95-ton tug EMERALD STRAITS which had sunk in April of that year with the loss of three men. Working in conjunction with a barge moored directly over EMERALD STRAITS, the submersible proceeded to cut two anchor chains from the tug, insert lifting lines through hawsepipes, and then maneuver a sling around and under the tug which had been lifted a few feet off the bottom by the surface barge. A total of 20 dives was required by PISCES to accomplish its task, one of which required her to surface and pick up a 60-pound lead weight in her mechanical arm which she used to literally pound a lifting mechanism through a hawsepipe. A total of 41 days elapsed from awarding of contract to surfacing of the tug.

Undoubtedly, the deepest and most dramatic salvage operation in the history of seagoing operations was effected by Reynolds International's ALUMINAUT on 22 August 1969 in 5500 feet of water off Cape Cod in the salvage of ALVIN.

Photographs supplied by a towed device from the USNS MIZAR showed ALVIN to be in salvageable condition, and ALUMINAUT was called in to assist. A lifting line with a toggle attached to the bitter end was strung from MIZAR on the surface down to the bottom 100 yards from ALVIN. ALUMINAUT dived, and inspected ALVIN and the surrounding area for obstacles. Taking the toggle, in one manipulator, ALUMINAUT literally crawled up ALVIN's side, cleared away obstacles and placed the toggle inside ALVIN's pressure hull. Receiving the signal that the lift was in place, MIZAR hauled away and successfully retrieved the 15-ton vessel.

INSTRUMENTS AND SYSTEMS TESTING

Virtually every dive in a manned submersible is directly or indirectly a test of instruments and systems, but a large number of dives have been for the specific purpose of testing. Many of these instruments and systems will have direct applicability to the forthcoming operations and effectiveness of the Navy's Deep Submergence Rescue Vehicle, (DSRV), the search vehicle (DSSV), NR-1, the submersibles SEA CLIFF and TURTLE, to fleet submarines, and, in some instances, to towed, unmanned vehicles.

Navigation - There are a multitude of proposed systems for determining the position of a submerged vehicle, but these systems are only as good as the paper they are written on until the concept and hardware have been tested and proved at-sea. Three basic systems have been tested; they consist of: 1) the submersible navigating relative to a fixed bottom marker, 2) the submersible being tracked by, and positioned relative to, a surface ship and, 3) a refined dead reckoning system using Doppler sonar. Bottom navigation by two precision-time controlled bottom-mounted pingers was developed by WHOI; it was tested aboard ALVIN on several dives and was used to assist in the search for an aircraft found on a previous dive. The aircraft was relocated and ALVIN's track during the search was recorded and reconstructed following the dive (Marquet, 1968). Synchronous pingers such as these offer the advantage of concurrent multi-vessel use of the system without interference. The Naval Oceanographic Office has developed a bottom-mounted transponder navigating system which has been tested on PC3-B, ALVIN, STAR III and ALUMINAUT (Merrifield and Delort, 1968). The system, consisting of three bottom-mounted transponders, a submersible-mounted interrogator/receiver and an internal range display/recorder, has been used to navigate ALUMINAUT during a bottom survey and later to reconstruct the track. The advantage of the transponder system is that it provides slightly greater range accuracy than the pinger system, but it cannot be used by several vehicles simultaneously. Another submersible-contained navigating system is Doppler sonar. The Deep Submergence System Project has conducted tests with such a system from ALUMINAUT and found that accuracies, determined by a fixed 3-D tracking range, ranged from ± 1% of the distance traveled in CW mode, and ± 2% in pulse mode (Sperry Corp., 1968). The tests further showed that the system used (Marquardt 330) was effective in the pulse mode between 8 and 475 feet altitude, and in the CW mode was effective between 8 and 160 feet altitude. Additionally, the source and magnitude of accuracy and repeatability errors was identified and, in some cases, corrected.

Systems and techniques of tracking a submersible from a surface ship have been approached in various ways by the submersible companies. The result is generally a pinger and transponder attached to the submersible to determine range and bearing from an interrogator and directional hydrophone on the surface (Marquet and Rainnie, 1969; Merrifield and Fagot, 1969). These systems, which are inexpensive, mobile, easy to operate, and require no assistance from the submersible, can be easily adapted to use in tracking fleet submarines during sea trials or tests, if required. For greater position accuracy ONR and General Motors (AC Electronics) have developed and employed with ALVIN and DOWB, respectively, three hydrophones and an interrogator on the surface ship to interrogate and receive from a transponder on the submersible, thereby obtaining three simultaneous slant ranges from which true range and bearing can be computed.

INSTRUMENTS AND EQUIPMENT

Whereas TRIESTE demonstrated that technology would allow safe penetration to any ocean depth, the task remained to demonstrate that such a capability was useful, and in this aspect a wide variety of scientific and operational equipment was required. Although most of the needed instruments and equipment were available, their use on submersibles was virtually nil, and many dives were required to determine their weak points, deficiencies and, in some cases, an entirely new design approach.

Operational Equipment - One of the first requirements was for external lighting for viewing, and a variety of lights, e.g., Birns & Sawyer, E.G.&G., and Hydro Products, was used, evaluated and modified until reliable light sources evolved. One of the more significant results of these operations was the Birns & Sawyer thallium-iodide light which responded to the need for greater viewing range and decreased power consumption.

Although previously used for mine detection from surface ships, the CTFM sonar found wide application to submersibles. One particularly significant modification was made to the DOWB CTFM which includes a range scale from 0-15 yards; this allows the submersible to vector within visual range of a target and still maintain a well-defined contact on the PPI display. With a scale of 0-50 yards, as is standard, one cannot distinguish outgoing from return ping well prior to visual contact and may spend hours searching for the contact while only 60 or 70 feet away. Obstacle avoidance sonar was needed in areas of reduced visibility; here the CTFM sonar was employed and operated by a variety of submersibles to who it has become a valuable tool for not only obstacle avoidance, but for navigation and search as well.

Other tests, through operations, of underwater telephones, manipulators, and various operational equipment have demonstrated available technological expertise and have indicated the source of strength and weakness in present equipment design and operation.

Scientific and Work Equipment - Very few instruments or equipment used to collect data or perform engineering tasks have been built for specific use on a submersible. Those that have are few in number and expensive owing to the limited market and, generally, a built-in level of funds for research and development. In the process of utilizing what is available, several aspects of instrument and vehicle design and performance have been identified; the following are considerations and deficiencies in design and aspects of operation, the knowledge of which is of direct benefit to the present vehicle and future design of military submersibles and equipment.

Vehicle Considerations:

- Hatch diameter (15" to 30" range) may be too small to insert equipment.
- High humidity, high temperature, and condensation/drippage of interior is detrimental to electrical instruments.
- Surges and spikes in vehicle-supplied power necessitates a voltage regulator in the instrument.
- Electrical and acoustical interference, present in almost all submersibles, can eliminate the use of many types of sensitive electro-acoustic instruments.
- Reliability in instruments is first order priority for there is generally no time, space, or spares to effect repairs during a dive.

Instrument Considerations:

- Unprotected (unfaired) instruments should be jettisonable.
- Lack of standardization in connectors and penetrators requires major overhaul for each different submersible.
- Shielded and balanced cabling for each instrument.
- Minimum size and weight.
- Modular (multi-package) should be the design goal.

In the course of a variety of operations many instruments and work tool systems have resulted which have direct application to military needs. Several of the most applicable of these have been the salvage tools and techniques evolved in the ALVIN recovery by ALUMINAUT and USNS MIZAR, and the routine recovery of torpedoes by PISCES.

PISCES further demonstrated the practicability of submersibles in salvage when she recovered the 95-ton tug EMERALD STRAITS from 670 feet depth. Besides benefiting in terms of hardware and techniques, the military salvage officer must more cautiously apply the term "unsalvageable" to an object. Such salvage accomplishments have demonstrated that salvage is only limited by the imagination and know-how of the personnel involved to combine what is now available into an effective system.

Specific instruments have evolved and have been tested which are applicable to primary and secondary missions of NR-1, the DSRV, and DSSV. Examples include the Water Sensor Pod (WASP) of NAVOCEANO, the Vane Shear Devices of Lockheed, WHOI and NURDC, and the wealth of knowledge in the lighting configurations, cameras and film types required for underwater photography. One major effort resulting in numerous hand tools and mechanical accessories for application on Naval vehicles is contained in the comprehensive report by C.L. Winget (1969 of WHOI (Fig. 7).

Vehicle/Systems Design - In the course of operations the strong and weak features of the wide variety of submersible designs and operational modes have been identified. Although this information has been used sparingly in construction of Naval submersibles, it is available at NURDC, NUSL, WHOI and NAVOCEANO. In one instance, the deficiencies in vehicle design, as pointed out by Busby (1968), have been noted and attempts have been made to avoid them (Blair, 1969) in the DSSV. Inadequacies noted through use of present vehicles have led to several projects in the Navy where attempts to overcome such features are being made. A case in point is the acrylic plastic pressure hull development at NCEL and the glass hemi-head, steel cylinder DEEPVIEW at NOTS, both of which aim at increased viewing capability and decreased weight.

That the submersible is only one component of a system which also includes the support ship and a launch/retrieval apparatus was amply demonstrated in the loss of ALVIN during launch. Consequently, the identity of launch/retrieval as the major problem in submersible operations must be dealt with in present and future Naval submersibles. Industry has produced a variety of devices for handling the vehicle from which the Naval designers can draw invaluable, at-sea-tested information.

Probably the most difficult problem to overcome in a multi-instrumented submersible is the interference, electrical and acoustic, produced in submersibles where no shielding or physical separation of penetrations exists. Virtually every submersible has interference problems which could have been avoided if the need was appreciated during design (K.R. Haigh, unpublished manuscript). This interference seriously detracts from the submersible's full usefulness to the point where some types of acoustic studies, for which the submersible would be the perfect platform, cannot be conducted. This problem has been particularly severe in NAVOCEANO operations where attempts to conduct operations with several instruments concurrently have been made. The problem has been identified, and its extent must be appreciated in design of Naval submersibles if multi-task dives are to be conducted. Such interference would present a serious problem in the DSRV where a wide variety of electro-acoustic systems will be required to operate synoptically.

Operations with the intent of conducting detailed topographic mapping, acoustically and photographically, have identified problems in vehicle and instrument design and control which will be directly applicable to similar military missions, perhaps anticipated with NR-1. In-flight stability is of highest priority when the data reduction stage is reached where level flight or, at least, detailed monitoring of all degrees of motion must have been accomplished in order to interpret the data obtained. The solution which this past experience has supplied to the Naval designer is basically quite simple: one must design a submersible with specific operational tasks in mind, rather than designing the tasks to fit a fait accompli "all purpose" submersible.

MATERIALS AND COMPONENTS

In the process of constructing, certifying and using submersibles several areas in materials and components have been advanced and improved by the vehicle owners that are of present and potential value to the Naval designer. One of the most obvious has been in the demonstrated acceptability of acrylic plastic, first used by Auguste Piccard in the early bathyscaphs, as viewports. Every present submersible uses acrylic plastic viewports, its forgiving nature being a major factor, and studies conducted by Snowey and Stachiw (1968) of NCEL showed it to be a prime candidate for the pressure hull itself. In this vein, NCEL has pushed ahead in its studies to the point where plastic has progressed from a Category III material to Category II in the NAVSHIP materials rating scheme. The application here is not only to submersibles, but lightweight instrument packages as well. Although it is not as easy to control its quality, glass also has progressed as a candidate for pressure hulls and the work of NOTS on DEEPVIEW is presently providing an insight to this material.

The use of aluminum had been questioned as a pressure hull material owing to the possibility of stress corrosion, particularly between the joints, which were bolted, rather than welded, together. But inspection of ALUMINAUT's hemi-head/cylinder joint dismantled after three years of diving showed that with proper protection and maintenance this problem was vastly overrated. Similarly, ALVIN's successful use of titanium spheres for hard ballast tanks over several years operation significantly increased the level of confidence in this material as a pressure capsule.

Naval requirements call for the use of Monel piping in submarine oxygen systems, but submersible manufacturers used the much less expensive stainless steel. To justify the less expensive material, J. Purcel and F. Kredit of NAVSHIPS assimilated sufficient data and information to demonstrate the certification acceptability of stainless steel for this use.

In the area of life support a great advance was made by Grumman's BEN FRANKLIN in the use of liquid oxygen and thin, suspended lithium hydroxide panels to support six men for a thirty-day period without the need for power-consuming blowers. Additionally, prior to BEN FRANKLIN's 30-day drift a maximum of 25 ppm carbon monoxide was considered the tolerable limit, but serious questioning of this limit, as it was approached and later exceeded, produced serious doubts and the value was upgraded to 50 ppm during the mission. It is granted that much work remains in the field of human tolerance to various gases, and the experiences of BEN FRANKLIN amplify the possibility of other deficiencies in our understanding of these phenomena.

One of the most significant contributions of submersibles to oceanographic engineering, in both equipment and submarines, has been the performance of penetrators and connectors on depths exceeding those reached by normal fleet submarines. Reliability of penetrators and connectors is a serious problem which has plagued deep submersible operators from the beginning (Thomas, 1969), and many manufacturers are reassessing their approach toward greatly improved reliability. The seriousness of this problem at depth was not truly appreciated until the advent and application of the deep-diving manned submersible, and successful design will have application to fleet submarines as well as noncombatant submersibles.

SUMMARY

SCIENTIFIC BENEFITS

Primarily, the scientific benefits of the submersible have been to reveal many of the shortcomings of surface-oriented sampling/measurement techniques, and to provide a clearer, more detailed picture of the environment; these benefits are listed below.

- An awareness of the operating environment has been provided which transcends the inferences of remotely obtained data.
- Topography obtained by wide-angle sonar, and possibly even narrow-angle, will not suffice on and below the continental shelf when objects of less then 100 ft. relief will be an operational obstacle.
- The dynamics of the deep ocean environment change rapidly and "representative" samples may well exist in concept only in many ocean areas.
- Remote sampling methods may, by the very nature of their operation, miss or destroy the organisms one wishes to study.

- Near-bottom ocean currents can undergo several orders of magnitude change in a few feet of lateral and horizontal distance, and in areas of submarine canyons, cliffs and escarpments, remote data sampling can only be considered representative of the area directly around the sensor.
- Although more investigations must be made, preliminary bottom reflectivity studies from submersibles indicate that much lower bottom losses are present than surface observations show. Standard deviations also point to the submersible as an ideal candidate platform for acoustic studies.
- Although anticipated, operations with submersibles have demonstrated that gravity measurements from these platforms provide accuracies as fine as $\pm$ 0.02 milligals.

<u>Submersible vs. Surface Platform: Mission Effectiveness</u>

- For detailed <u>in situ</u> examination and identification of hardware, wreckage, or instruments, there is no present system which can parallel the manned submersible/human eyeball combination.
- The "inflight" control of a manned submersible offers the ability to conduct fine-grained mapping and investigations all but impossible from surface platforms or lowered/towed devices.
- Search and salvage operations have conclusively demonstrated that the manned submersible closes the loop in which the surface ship locates the general area of interest, the towed device pinpoints the specific area or object of interest, and the submersible provides the dexterity and maneuverability to assist or effect retrieval of the object.
- The judgement "unsalvageable" cannot rely upon historical surface-oriented methods, e.i., wire rope drags, but must be applied in the light of the individual's imagination, expertise, and, not the least important, funds available, because all the components necessary for virtually any type of salvage are now available.

<u>Support Systems and Instrument</u>

- Systems have been developed and tested for on-board navigation (bottom-mounted) or remote tracking (surface ship-mounted) of submersibles or towed devices for search, surveying or rescue missions. Knowledge of how and when to use which type of navigation system has also evolved.
- Acoustic and photographic systems and illumination devices have been developed, tested and improved for a variety of military oceanographic tasks.
- Operational instruments such as underwater telephones and manipulators have been demonstrated to perform at great ocean depths which have application to fleet submarines, as well as mission-oriented submersibles.
- The unique operational and environmental constraints for submersible instrumentation have been identified through experience, and the knowledge exists to improve all systems for greater performance and reliability.
- Tools and techniques have been developed and tested for salvage and selective retrieval of objects or samples from the deep ocean floor.
- At-sea experience with a variety of launch/retrieval systems is available for improvements to future systems involved with either submersible or large object over-the-side operations.

<u>Vehicle Design and Materials/Components</u>

- Deficiencies and assets have been reported from a wide variety of design approaches which are of direct benefit to design of future manned submersibles.
- The severe problems of conducting sensitive electro-acoustic experiments from submersibles with high electric and acoustic interference potential has been identified and must not be repeated in forthcoming manned or unmanned vehicles.
- Materials have been used on submersibles to the point where a degree of confidence has been attained that allows their advantageous inclusion in submarines and instrument packages.
- Operations have been conducted, such as photogrammetric mapping, which delineated the degrees of control required for various missions and the concurrent monitor-

ing required of vehicle motion to successfully interpret the results.

- The importance and rarity of reliable, rugged electrical penetrators and connectors have been brought to light by deep-diving submersibles, and the efforts to improve their performance has been initiated. Such improvements are of direct application to fleet submarines as well as lowered instrument packages.
- A variety of approaches to life support and environmental monitoring/tolerance have produced systems of present and potential value to undersea military oceanographic and tactical operations.

CONCLUSION

The manned submersible has provided a broad spectrum of benefits to military oceanography far in excess of the few million dollars expended for their lease and operation. They have provided direct benefits in the form of environmental data, materials, instruments and technology, and indirect benefits in the form of instigating the need for new approaches to studying and working within the ocean. It remains for the military oceanographer to utilize this knowledge to its full extent. More importantly, it is incumbent on the administrator and planner to recognize that the manned submersible is not an engineering toy, but an unparalleled tool which is as unique in its ability to conduct detailed studies and tasks underwater as is the aircraft's ability to fly.

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TABLE I

SUBMERSIBLE DIVES BY USERS

Activity	ALUMINAUT	ALVIN	BEN FRANKLIN	DEEP DIVER	DEEPSTAR-4000	DIVING SAUCER	DOWB	PC3-B	PISCES	STAR II	STAR III
NURDC					244						
NUSL		15			56	16		7			31
NAVOCEANO	34	19	124 (30-day drift)		13			21			19
DSSP	32				8						
NCEL					9						
AUTEC	5										
SP. PROJECTS	25										
SUPSALV				3				42		6	11
NAUTORPSTA									68		
NSRDC								3			
ONR/WHOI		266					1		15		
NUWS		6									
DTMB		1									

TABLE II

SUBMERSIBLE DIVES BY MISSION

SUBMERSIBLE	Search/ Salvage	
ALUMINAUT	(H-Bomb) 25	
ALVIN	(H-Bomb) 34	(Arm) 4
BEN FRANKLIN		
DEEP DIVER	3	
DEEPSTAR-4000		
DIVING SAUCER		
DOWB	(ALVIN)	
PC3-B	(H-Bomb)	

TABLE II

SUBMERSIBLE DIVES BY MISSION

SUBMERSIBLE	Search/ Salvage	Equip. Test	Survey/ Explore	Acoustic Studies	Geologic Studies	Biologic Studies	Physical Studies	Hardware Inspect.	Nav. Studies	Operational Support	Photo-graphy	Survey/ Equip. test	Test Orient.
ALUMINAUT	(H-Bomb) 25	32	27					5	7				
ALVIN	(H-Bomb) 34	(Arm) 4		5	43	38	6	18	10		4		145
BEN FRANKLIN												(Drift) 124	
DEEP DIVER	3												
DEEPSTAR-4000				319						(SEALAB III) 8	3		
DIVING SAUCER				16									
DOWB	(ALVIN)												
PC3-B	(H-Bomb) 42		11					10	10				
PISCES	(torpedo) 64							19					
STAR II	(NIMBUS) 6												
STAR III	(Thule) 11			31					5		14		

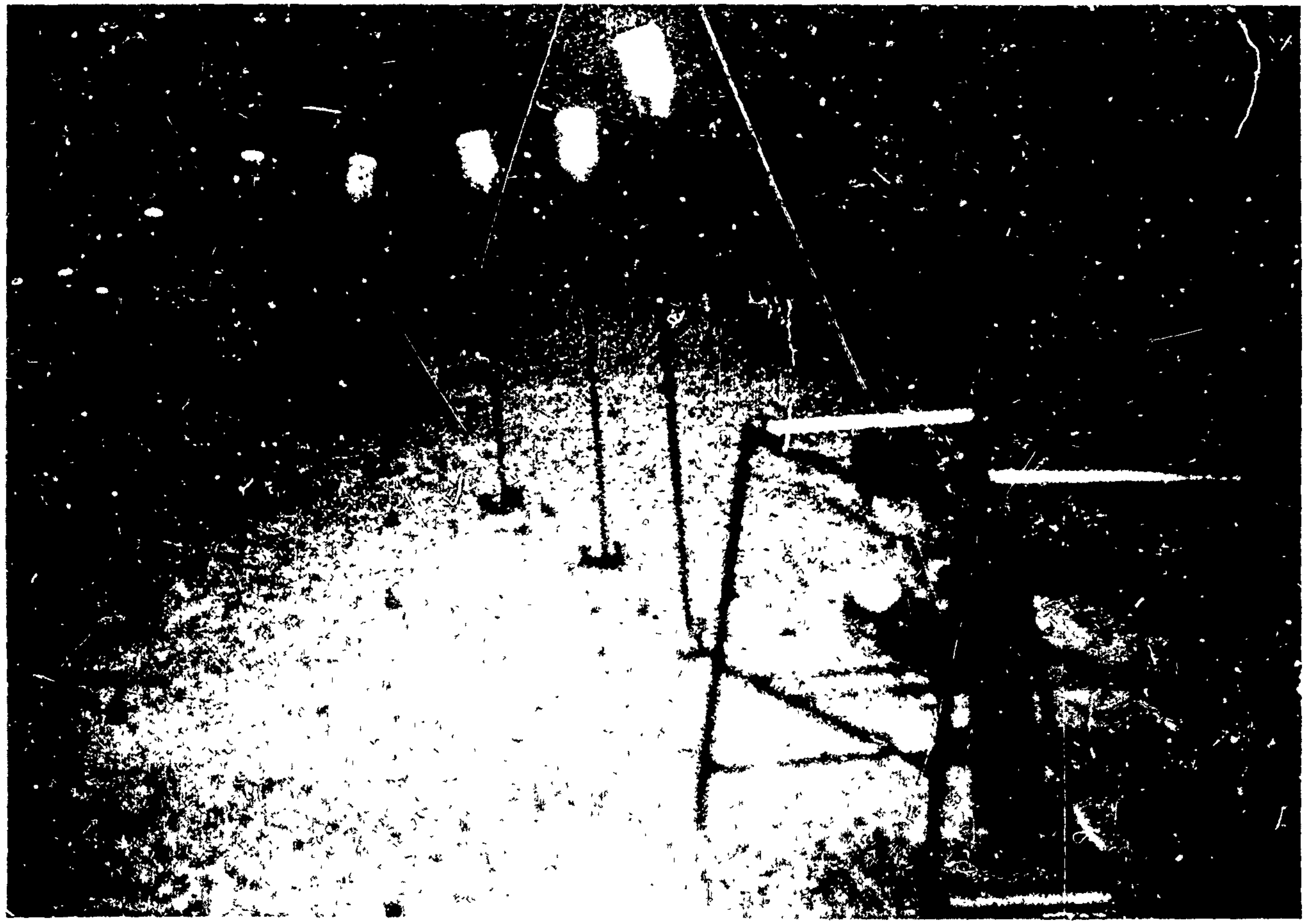


Figure 1. Array at 600 feet depth off Key West. Bottles are at intervals, of ten feet, photo taken under natural light. Estimated horizontal visibility range exceeded 200 feet.

Figure 2. The base of an AUTEC array adjacent to a rock outcrop at 5000 feet which clearly demonstrates the "hit or miss" nature of installing-hardware from the surface. (NUS photo from ALUMINAUT)

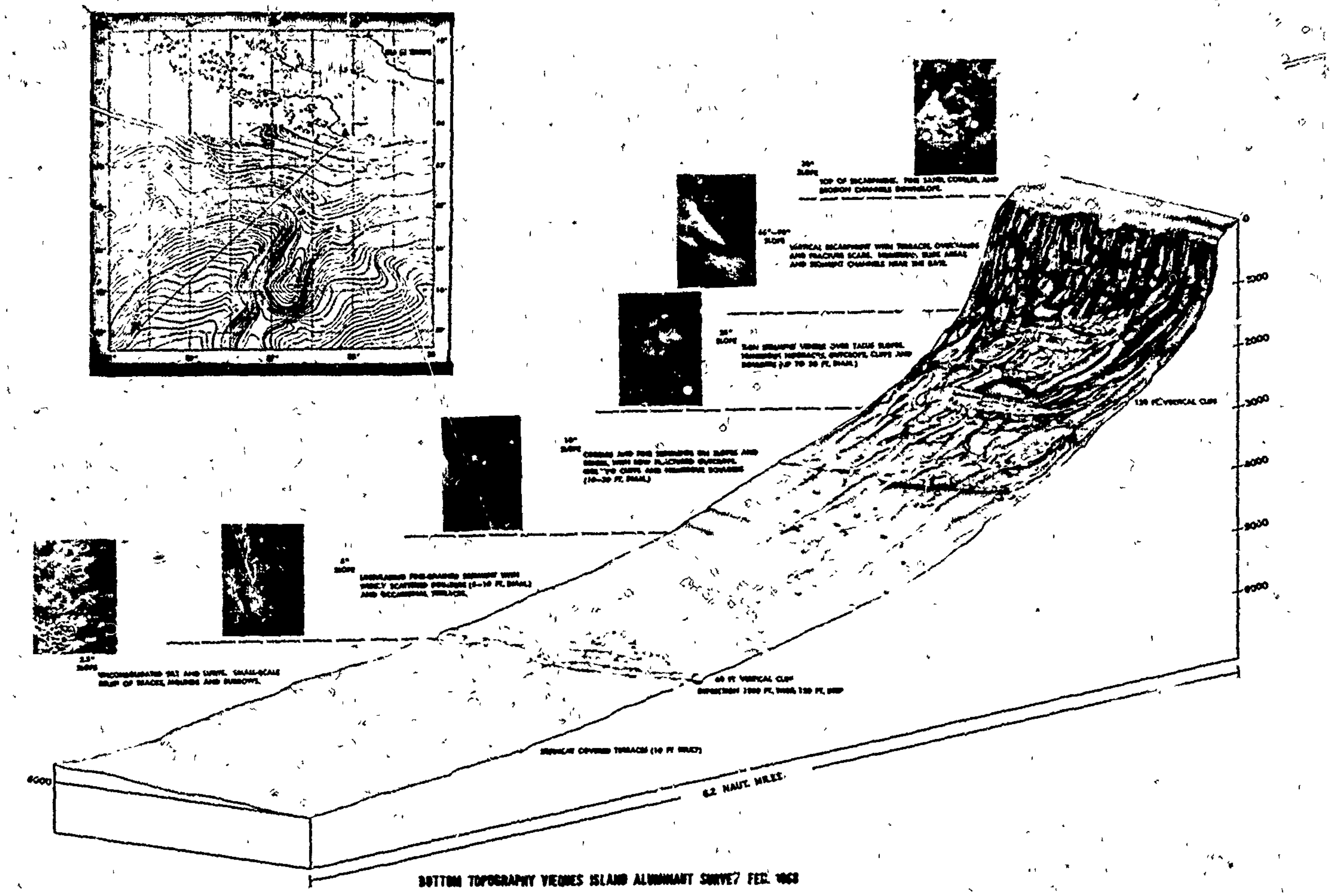


Figure 3. The results of a submersible survey along line A-A' in the inset. The contour chart was obtained by conventional surface techniques.

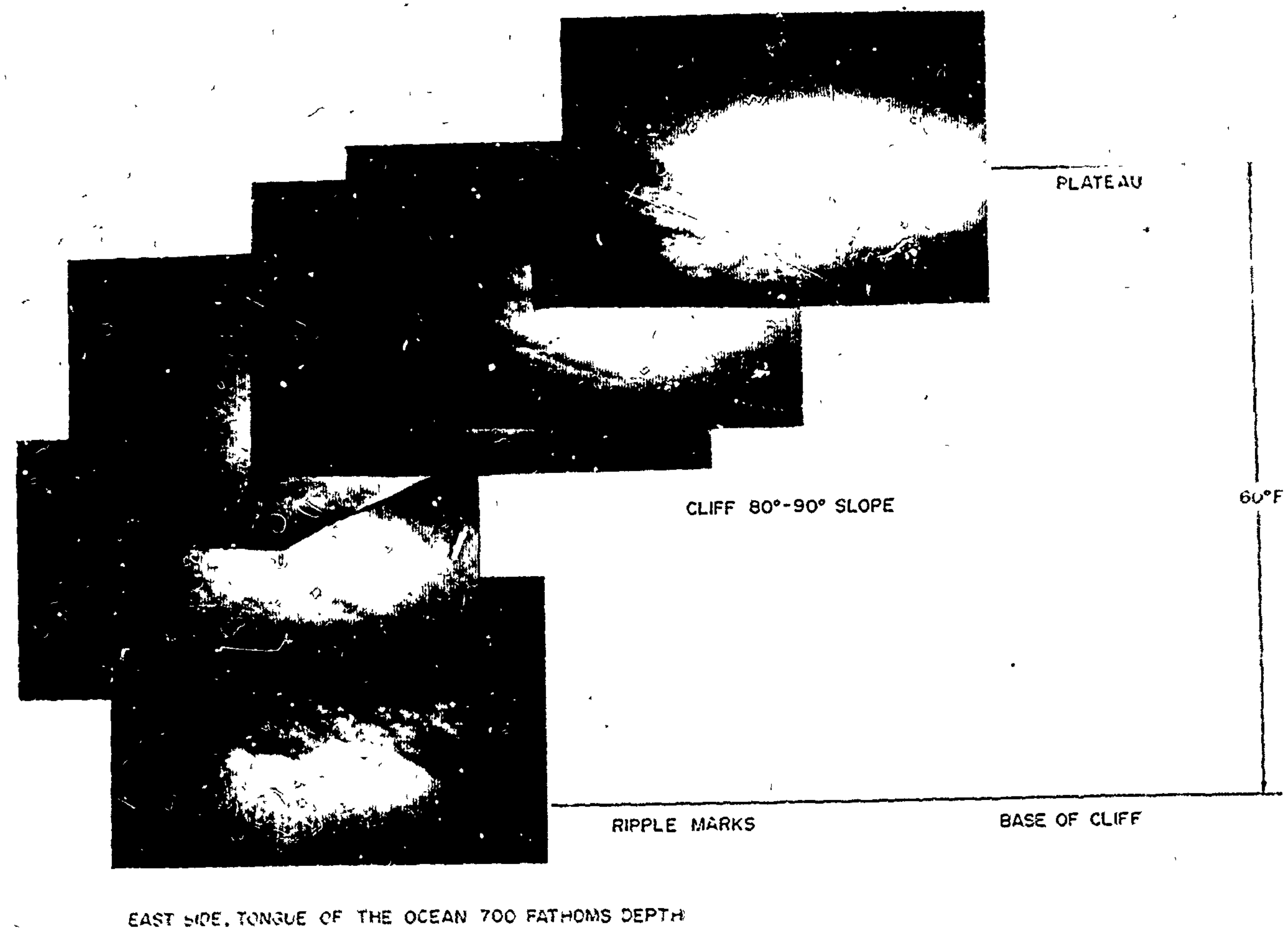
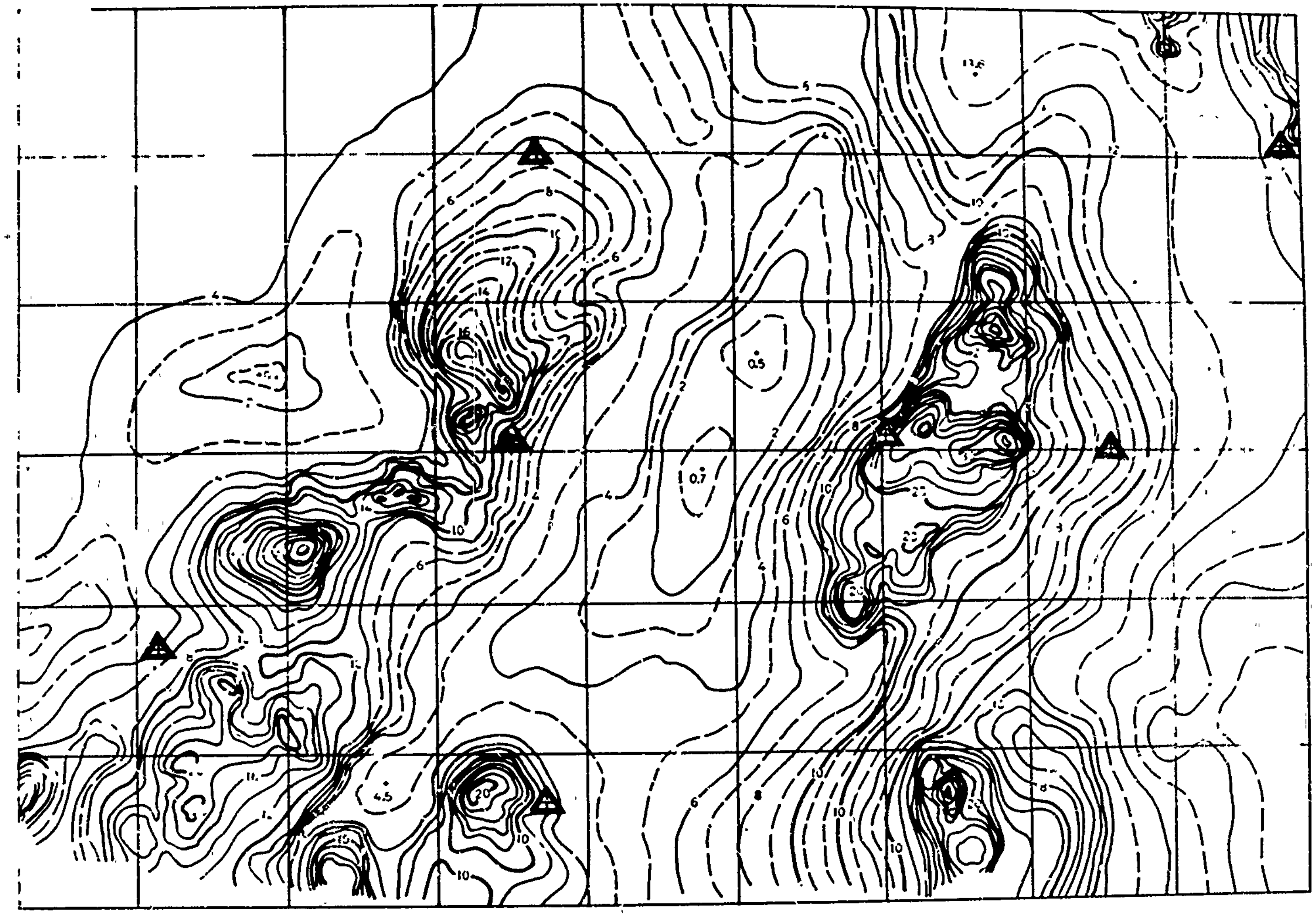
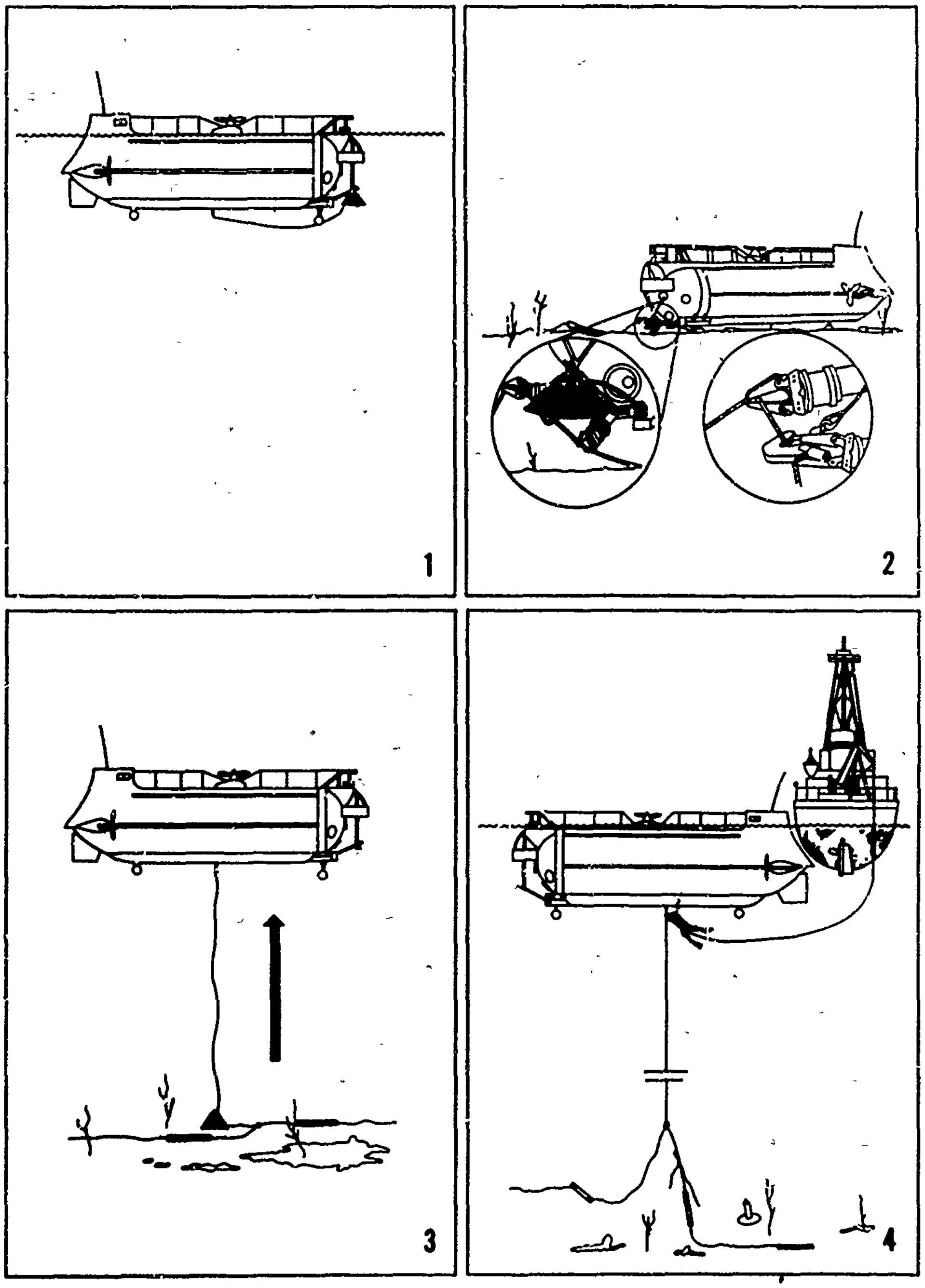


Figure 4. Demonstrating the variability in currents at the base and top of a 60 ft. high escarpment. A current speed of 0.4 knots was measured at the base; the current was too slow to be measurable at the plateau.



UNDERWATER TOPOGRAPHIC MAP
(REFERENCE LEVEL 32 FEET BELOW SEA LEVEL)

Figure 5. Micro-topographic chart of an undersea area in the Bahamas. Grid interval 4.5 feet, contour interval 2 inches (1 inch supplement).



INSTRUMENT PLANT AND RETRIEVAL

Figure 6. The technique used by ALUMINAUT to retrieve a lost current meter array at 3150 ft. depth in the Virgin Islands.

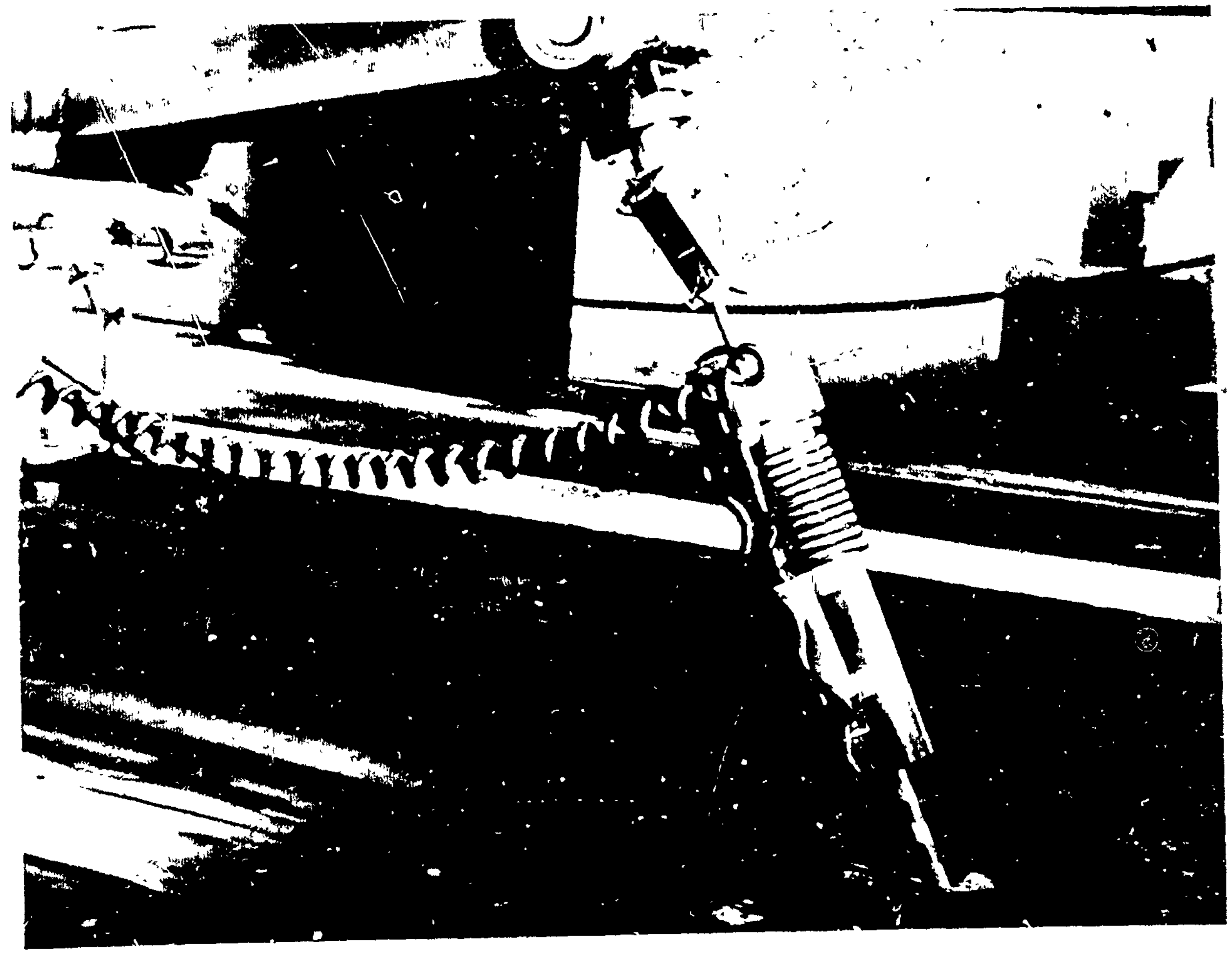


Figure 7. Hard rock corer developed by Woods Hole Oceanographic Institution and successfully used from ALVIN.

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